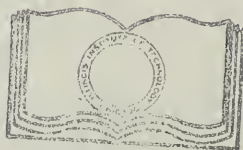


DESIGN OF A 15,500 KW.
GENERATING STATION

BY
ALLAN GRANT
A. J. SUGARMAN

ARMOUR INSTITUTE OF TECHNOLOGY
1920

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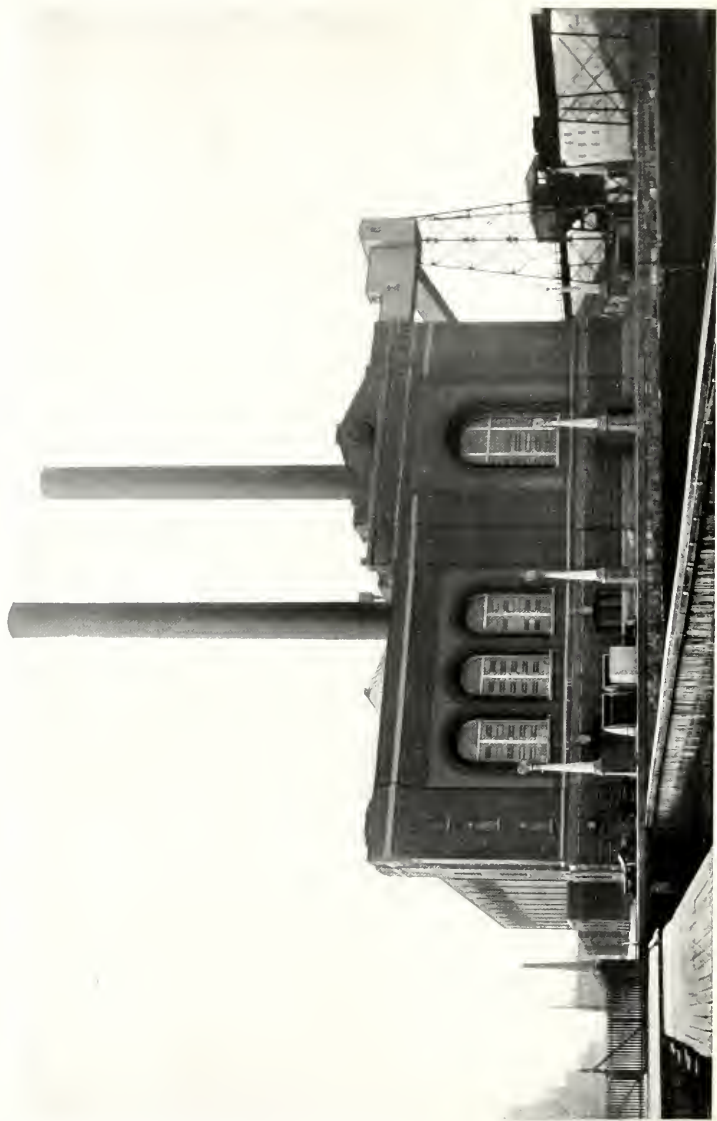
Grant, A. Q.

The design of a 15,500 Kw.
generating station with a

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THE DESIGN OF A 15,500 KW. GENER- ATING STATION WITH A 2,000 KW. D. C. RAILWAY SUBSTATION

A THESIS

PRESENTED BY
ALLAN Q. GRANT AND ABRAHAM J. SUGARMAN
TO THE
PRESIDENT AND FACULTY
OF
ARMOUR INSTITUTE OF TECHNOLOGY
FOR THE DEGREE OF
BACHELOR OF SCIENCE
IN
ELECTRICAL ENGINEERING

MAY 27, 1920

APPROVED:

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Professor of Electrical Engineering

Dean of Engineering Studies

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OUTLINE OF WORK

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Conditions Underlying design.

Part 2

Selection and Specifications of Power Generating Equipment and Auxiliaries, Including All Steam Driven Apparatus.

Part 3

Electrical Equipment of Main Station.

Part 4

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Part 5

Description of Building and Layout of Apparatus.

Part 6

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PART 1
OBJECT OF THESIS

The object of this thesis is the design and specifications for a steam electric generating station for the generation of electric power for both lighting and general power service. Included in the same thesis is the design and specifications for a substation for the utilization of the central station power output in the operation of a D. C. 600 volt railway system.

The design will be general only to the extent that the geographical position is not specified, and that several means are considered for obtaining a given desired result. The best equipment for this particular installation is specified in each individual case, all important factors tending to govern a choice having been considered.

There are several conditions governing the design of the station. These conditions are given below.

- (1) The units chosen shall be able, at all times, to carry, as a whole, the total K W. output. The choice of units shall be so governed as to permit of the greatest overall efficiency of the plant, in accordance with the loads given by the load curve. (See Fig. 1)
- (2) The total full rated load output is to be 15,000 K W., 900 K W., of which is to meet the lighting requirements.
- (3) The total A. C. line length is 100 miles,

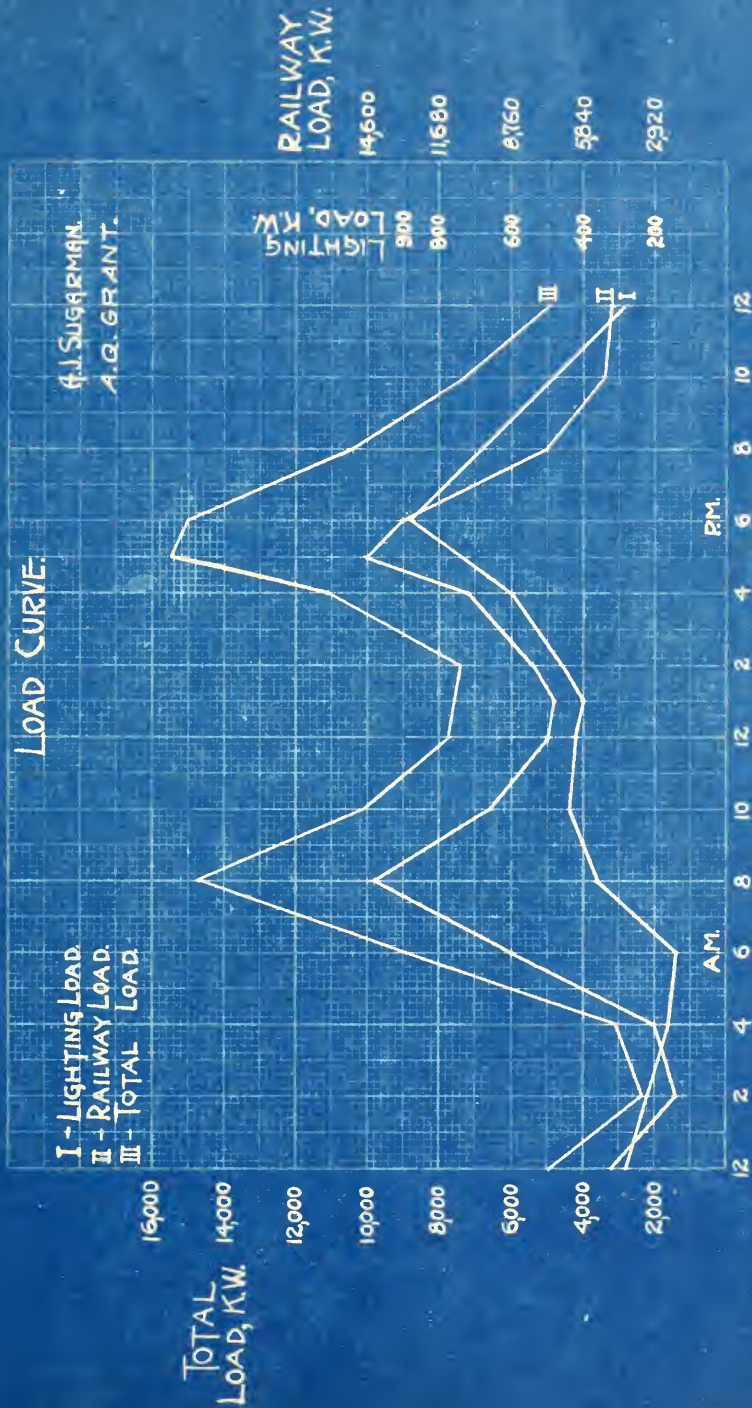


Fig. 1

with the station situated 40 miles from one end, and 60 miles from the other end. Provision is to be made for double feeders to protect against breakdowns and consequent delays due to line troubles.

(4) A substation equipment must be supplied for the conversion of alternating current at the low-tension voltage to direct current at 550-600 volts, the direct current output to equal 2,000 K W. rated load. This substation equipment is to be situated in the main station.

(5) All equipment and construction must conform with the standardization rules of the A. I. E. E.

PART 2

BOILERS

The requirements of an ideal steam boiler are:

(1) Proper workmanship and simple construction, using materials which experience has shown to be the best, thus avoiding the necessity of early repairs.

(2) A mud drum to receive all impurities deposited from the water, and so placed as to be shielded from the action of the fire.

(3) A steam and water capacity sufficient to prevent any fluctuation in steam pressure or in water level.

(4) A water surface for the disengagement of the steam from the water, of sufficient extent to prevent foaming.

(5) A constant and thorough circulation of water throughout the boiler so as to maintain all parts at the same temperature.

(6) The water space divided into sections so arranged that, should any section fail, no general explosion can occur and the destructive affects will be confined to the escape of the contents. Large and free passages between the different sections to equalize the water line and pressure in all.

(7) A great excess of strength over any legitimate strain, the boiler being so constructed as to be free from strain, due to the unequal expansion, and, if possible, to avoid joints exposed to the direct action of the fire.

(8) A combustion chamber so arranged that the combustion of the gasses started in the furnace may be completed before the gasses escape to the chimney.

(9) The heating surface, as nearly as possible, at right angles to the currents of heated gasses, so as to break up the currents and extract the entire available heat from the gasses.

(10) All parts readily accessible for cleaning and repairs. This is a point of greatest importance as regards safety and economy.

(11) Proportioned for the work to be done, and capable of working to its full rated capacity with the highest economy.

(12) Equipped with the very best gauges, safety

valves and other fixtures.

The essential constructive difference between water and fire-tube boilers lies in the fact that the former is composed of parts of relatively small diameter, as against the large diameters necessary in the latter.

The factor of safety of the boiler parts which come in contact with the most intense heat in the water-tube boilers can be made much higher than would be practicable in a shell boiler. Under the assumptions considered in connection with the thickness of plates required, a number 10 gauge tube (0.134 inch), which is standard in Babcock and Wilcox boilers for pressures up to 210 pounds, the safe working pressure for the tubes is 870 pounds per square inch, indicating the very large margin of safety of such tubes as compared with that possible with the shell of a boiler.

A further advantage is the water-tube boilers as a class is the elimination of all compressive stresses. Cylinders subjected to external pressures, such as fire tubes, or the internally fired furnaces of a certain type of boilers, will collapse under a pressure much lower than that which they could withstand if it were applied internally. This is due to the fact that if there exists any initial distortion from its true shape, the external pressure would tend to increase such distortion and collapse the cylinder, while an internal pressure tends to restore the cylinder to its original shape.

Stresses due to unequal expansion have been a fruitful source of trouble in fire-tube boilers.

In boilers of the shell type, the riveted joints of the shell, with their consequent double thickness of metal exposed to the fire, gives rise to serious difficulties. Upon these points are concentrated all strains of unequal expansion, giving rise to frequent leaks, and oftentimes to actual ruptures. Moreover, in a case of such rupture the whole body of contained water is liberated instantaneously, and a disastrous and usually fatal explosion results.

Further, unequal strains result in shell or fire-tube boilers due to the difference in temperature of the various parts. This difference in temperature results in the lack of positive well defined circulation. While such a circulation does not necessarily accompany all water-tube designs, in general, the circulation in water-tube boilers is much more defined than in fire-tube or shell boilers.

A positive and efficient circulation assures that all portions of pressure parts would be at approximately the same temperature, and in this way strains resulting from unequal temperatures are obviated.

If a shell or fire-tubular boiler explodes, the apparatus as a whole is destroyed. In the case of water-tube boilers, the drums are ordinarily so located that they are protected from the intense heat and any rupture is usually in the case of a tube. Tube failures, resulting from blisterers or burning are not serious in their nature. Where a tube ruptures because of a flaw in the metal, the result may be more severe,

but there cannot be the disastrous explosion such as would occur in the case of an explosion of a shell boiler.

The requirement probably next in importance to safety in a steam boiler is economy in the use of fuel. To fulfill such a requirement, the three items of proper grate for the class of fuel to be burned, a combustion chamber permitting complete combustion of gasses before their escape to the stack, and a heating surface of such a character and arrangement that the maximum amount of available heat may be extracted, must be co-ordinated.

Fire-tube boilers from the nature of their design do not permit the variety of combinations of grate surface, heating surface, and combustion space possible in practically any water-tube boiler.

In securing the best results in fuel economy, the draft area in a boiler is an important consideration. In fire-tube boilers this area is limited to the cross sectional area of the fire-tubes, a condition further aggravated in a horizontal boiler by the tendency of the hot gasses to pass through the upper rows of tubes instead of through all of the tubes alike. In water-tube boilers the draft area is that of the space outside of the tubes and is hence much greater than the cross section area of the tubes.

Due to the generally more efficient circulation found in water-tube than in fire-tube boilers, rates of evaporation are possible with water-tube boilers that cannot be approached where fire-tube boilers are employed.

Another important result of better circulation ordinarily found in water-tube boilers is in their ability to raise steam rapidly in starting and to meet the sudden demands that may be thrown on them. In a properly designed water-tube boiler, steam may be raised from a cold boiler to 200 pounds pressure in less than one-half hour.

In the "Requirements of a Perfect Steam Boiler", the necessity for complete accessibility to all portions of the boiler for cleaning, inspection and repair, is demonstrated.

When the great difference is realized in performance both as to economy and capacity, of a cleaned boiler, and one in which the heating surfaces have been allowed to become fouled, it may be appreciated that the ability to keep heating surfaces clean internally and externally is a factor of highest importance. Water-tube boilers are, from the nature of their design, more readily accessible to cleaning than are fire-tube boilers. In fire-tube boilers the tubes are frequently nested together with a space between them often less than one and a quarter inches, and, as a consequence, nearly the entire surface is inaccessible. When scale forms upon such tubes it is impossible to remove it completely from the inside of the boiler, and if it is removed by a turbine hammer there is no way of knowing how thorough a job has been done. With the formation of such scale there is danger through overheating and frequent tube renewals are necessary.

The objections given above in the consideration of the inability to properly clean fire-tube boilers, holds as well for the inspection of such boilers.

The lack of accessibility in fire-tube boilers further leads to difficulties where repairs are required.

In fire-tube boilers renewals are a serious undertaking. The accumulation of hard deposit on the exterior of the surfaces so enlarges the tubes that it is oftentimes difficult, if not impossible, to draw them through the tube sheets, and it is usually necessary to cut out such tubes as will have access to the one which has failed, and remove them through the man hole.

In case of a rupture in a water-tube boiler, the loss will ordinarily be limited to one or two tubes which can be readily replaced. In considering the proper repair cost of the two types of boilers, the facts should not be overlooked that it is poor economy to invest large sums of money in equipment that, through a possible accident to the boiler, may be wholly destroyed or so damaged that the cost of repairs, together with the loss of time while such repairs are being made, would purchase boilers of absolute safety and leave a large margin besides. The possibility of loss of human life should also be considered.

The water-tube boiler also has the important advantage of taking up less space than the fire-tube type.

As the Babcock and Wilcox boilers live up to the above specifications, which are standard, the authors will use their boilers.

The full load capacity of the plant is 15,500 K W. allowing 3.5 K W. to one B. H. P., the required boiler horsepower

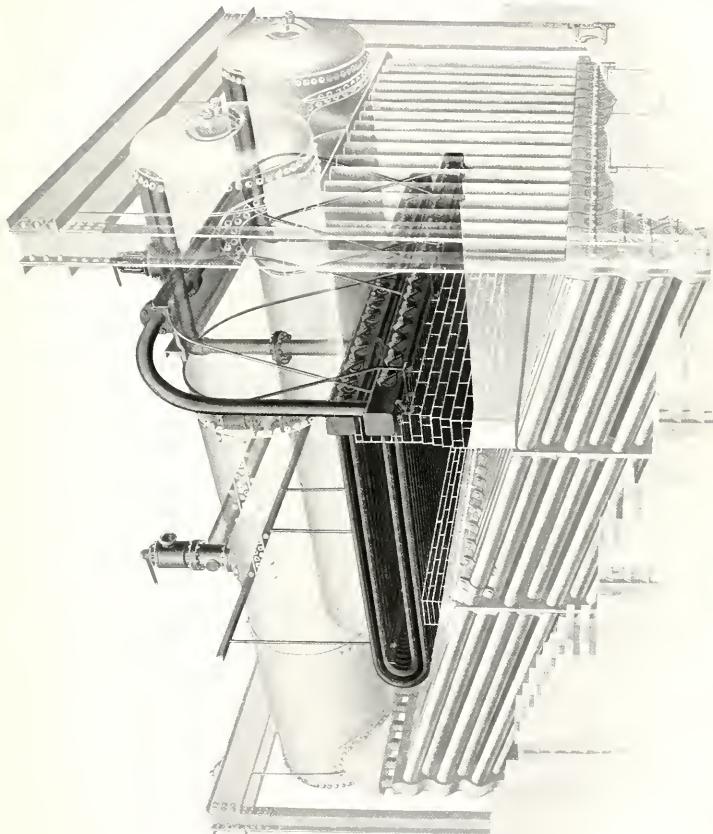


Fig. 2

is equal to $15,000 \div 3.5$, equals 4,428.

Using 500 B. H. P. units, we require $4,428 \div 500$ or 9 units in service at peak load. In order to allow for cleaning of the boilers, for repairs in case of breakdown, and for enlargement of the plant, an extra unit will be installed, making a total of 10-500 B. H. P. units or 5,000 B. H. P.

The above boilers will be equipped with super-heaters. Super-heated steam has a decided advantage over saturated steam, in the efficiency of operation, in the fuel saving per H. P. output of the engines. Savings of 20% and higher have been obtained with steam super-heated to only 113 degrees Fahrenheit. Our plant will use steam super-heated 200 degrees Fahrenheit. In spite of the fact that it takes 10.58% more fuel to super-heat 200 degrees Fahrenheit, the added efficiency in heat units more than offsets, in the majority of cases, the first cost, the upkeep and the added fuel consumption.

Aside from the fact that experiments and tests have shown the saving due to the use of super-heated steam, experience in a large percentage of modern plants shows this to be true. Our super-heaters will be standard Babcock and Wilcox equipment designed to give a super-heat of 200 degrees Fahrenheit. This super-heater is an intergral part of the boiler, as the saving with this type of construction is about twice as great as with separately fired super-heaters.

A standard installation of a boiler equipped with a super-heater is shown in figure 2, showing location, method of support and connections. Figure 3 shows a Babcock and Wilcox

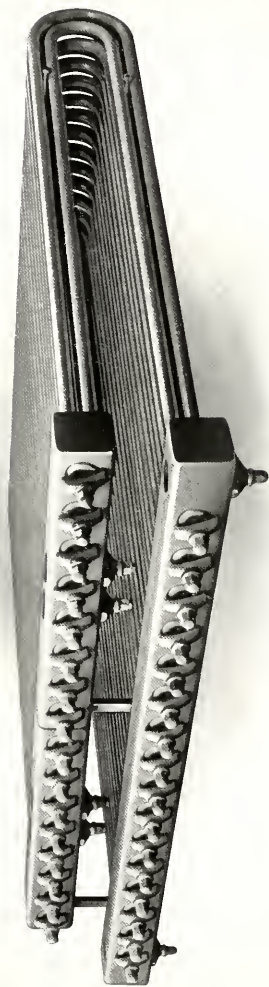


Fig. 3

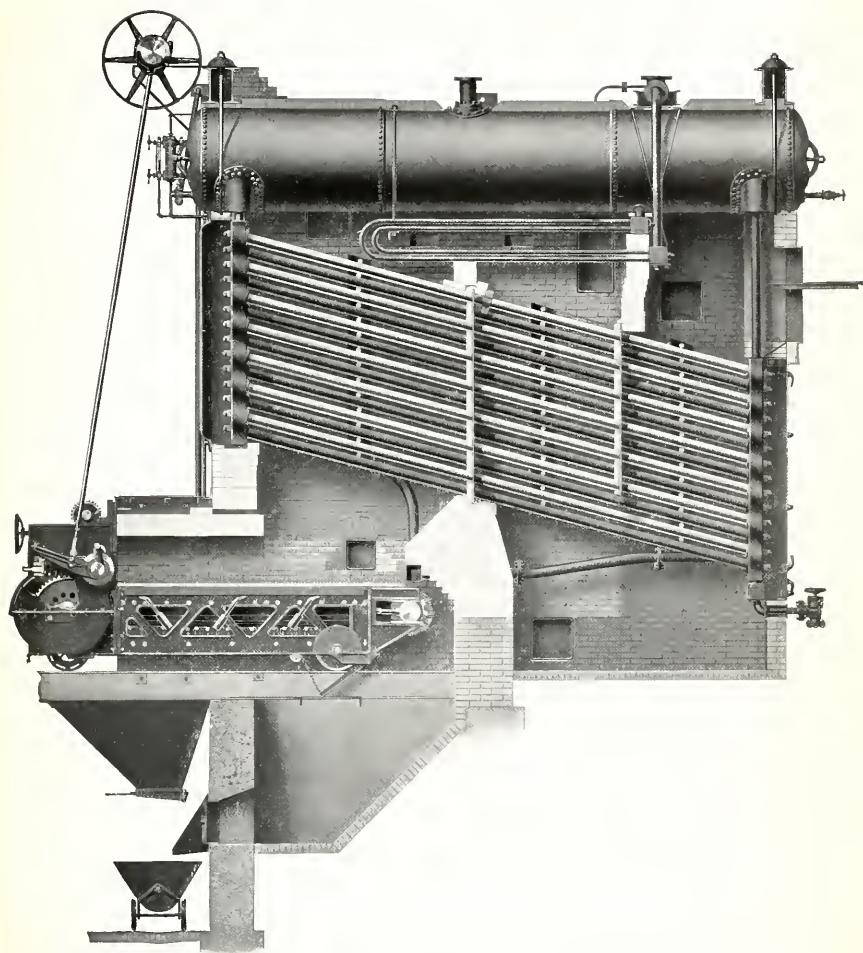


Fig. 4

super-heater, used in this plant, as applied to Babcock and Wilcox boilers. Figure 4 shows a sectional view of a complete boiler with super-heater.

GRATE EQUIPMENT

Of the large number of types of grates available for grate equipment, the authors have decided on the standard Babcock and Wilcox chain grates. All grates are for the purpose of automatically firing the boilers in such a way as to obtain the greatest fuel efficiency, to prevent smoke by properly caring for the spreading of coal and mixture with air, and to save labor.

Babcock and Wilcox grates are designed for the best and most efficient operation of Babcock and Wilcox boilers. Although others may be used, Babcock and Wilcox grates are a part of the Babcock and Wilcox boiler equipment. The grates used will be sufficient size to run the boilers at 225% load. This latter condition is met as standard equipment for the 500 horse-power boilers.

CONVEYOR SYSTEM

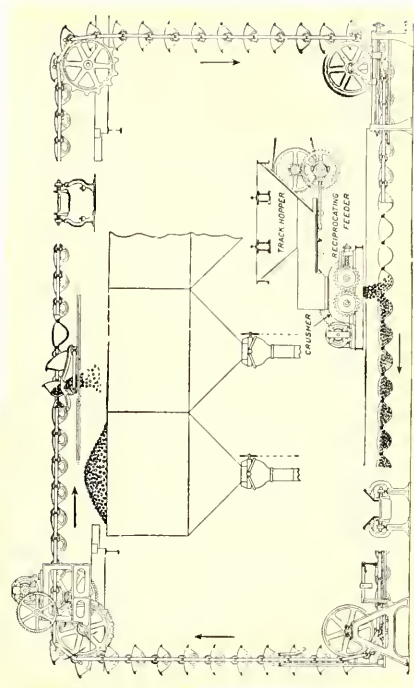
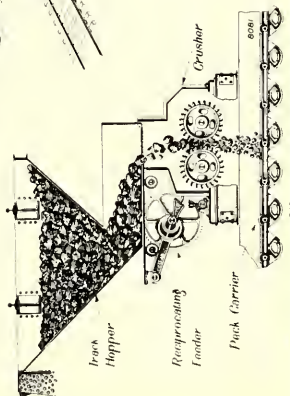
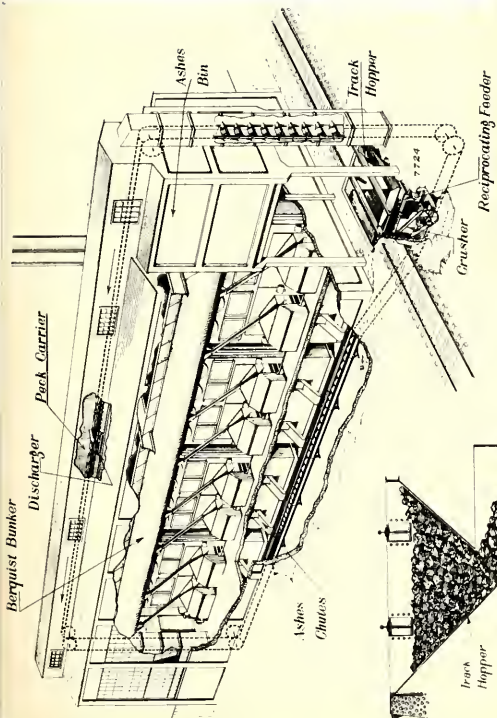
The science of handling coal and ashes economically at power plants, including the providing of suitable storage facilities, has progressed to a remarkable degree in the last few years. The results aimed at are the added profits to be obtained by saving expense in the handling, bu increasing the efficiency in the boilers, and by providing a storage that



will insure continuous operation and eliminate actual or threatened interruptions, which run into expense so rapidly. The point of cold storage is not quite as clean cut as the other points, because it is a question whether the expense of maintaining the coal storage will be justified in locations where the daily supply is regular and unlikely to be interrupted. In some cases the facilities for receiving or purchasing coal depend more or less on the season, so that it may not be convenient to get coal, for instance, in Winter, and in such cases storage plants should be provided with a capacity large enough to furnish the supply during the time when coal is not coming in.

Mention has been made of the possibility of increasing the efficiency of boilers by getting a better combustion in the furnaces. This is a possible saving of a considerable amount. It is safe to say that in a mechanically operated plant, using one man to fire two boilers, the fuel efficiency would be enough greater than when operating with one man for three boilers, to more that offset the extra cost of labor, and, in either case, the fuel efficiency would be better than in a plant where each fireman had to shovel coal into the stoker hoppers, as this work is so heavy that the actual working of the fires would be neglected, and the fires would not be kept in proper condition for their efficient operation.

Bucket Conveyors: The best modern practice in nearly all plants is to use first-class pivoted-bucket-carriers, traveling in a rectangular path, with the upper run above the



Figs. 7 and 8

coal and ashes bin and the lower run in the basement, where the ashes can be raked into it. In this way all the elevating and conveying of coal and ashes is done with one machine. (See Figures 7 and 8)

The conveyor to be used in the plant is a 24"x24" Peck pivoted bucket carrier, following a rectangular path, having horizontal centers of 198 feet and vertical centers of 79 feet, this carrier being driven by a 15 H. P. motor.

The coal crusher has chilled cast iron rollers, 28 inches in diameter by 24 inch face, and is driven by a 15 H. P. Motor. After the coal goes through the crusher it goes to the overhead bin, by means of the conveyor, and is then spouted direct to the stockers. The conveyor operates at a speed of 50 feet per minute, and has a capacity of 80 tons an hour of coal, or an equivalent volume of ashes.

The track hopper which is 20 feet by 18 feet at the top, is in a pit below the ground level, so that the cars can be placed over this hopper and the coal dumped into it. The coal is then fed by a reciprocating feeder to the crusher, and goes through the crusher into the carrier, which elevates it and distributes it in the overhead bin or hopper. The ashes go from the ash hoppers into the lower run of the carrier, and are taken up and delivered to the bin over the railroad track, from which they can be delivered to the cars at any time desired.

By the use of a reciprocating feeder underneath the bottom of the track hopper, the coal is fed regularly and automatically to the crusher, no matter what the size of the

lumps may be, and in this way the crusher receives a regular feed and does not become choked. It can, therefore, be driven with a moderate amount of power.

Link-Belt equipment is specified for use in the plant.

STORAGE BINS

The coal bins or hoppers are designed for maximum strength, without the use of posts or other vertical supports. The bins are supported by horizontal girders, as shown in the elevation view, and the sides of the bins strengthened against bulging by the use of angle irons riveted into the bin plates and placed horizontally and on all sides of the bin. This arrangement of the bins can be plainly seen on several of the cuts of boiler rooms. Sometimes these bins are lined with concrete or other material to avoid corrosion, and, in one design, the body of the bin is built of reinforced concrete with straps or saddles hung from the girders at the top edge to take the majority of the weight. Most of these bins, however, are built of steel plates only, and they are specified for use in the plant being designed. The ash hopper will be built of concrete, however, because the corrosion caused by wet ashes would soon ruin an iron hopper.

A weighing hopper should be provided so that accurate boiler tests may be made and a check had on the efficiencies of the different units. There are two general methods in use at the present time; one is a traveling hopper



which is supported by scale beams and can be moved along the track and used to weigh the coal going into any boiler; the other method of weighing the coal is with the use of an automatic self-recording scale in connection with the coal bin spout. In the plant being designed, we will use the first method mentioned, as this is cheaper in the long run, and can be used on all the stokers instead of on just certain ones.

TURBINES

As specified in other cases, General Electric machinery will be used throughout, where electrical equipment is required. Therefore, Curtis turbines are specified.

The advantages of the Curtis turbine are:

Economy.

(1) Highest initial efficiency maintained in service.

The steam economy of Curtis turbines varies somewhat with the size of the unit, and in small machines is relatively less than in large because of the larger percentage of losses and desirability of simplifying the design. All sizes are designed for the highest economy, consistent with the class of service for which intended.

While all turbine buckets may be subject to wear under the erosive action of very wet steam, or due to corrosion from acids and impurities in the steam, Curtis buckets are adapted to withstand this action. Their very large section permits a certain amount of wear without greatly

altering the contour of the steam passages, and without appreciable effecting the economy. On the other hand, an equal amount of wear on a bucket of small section changes its shape, with resulting loss in efficiency. The end clearance of the buckets is such that contact will not occur where the radial clearance is small.

(2) High steam economy, over wide range of loads.

The principal of the turbine and the system of governing in particular, result in the highest obtainable economy, over a wide operating range of load. Since there is practically no throttling at light load, and only the correct number of valves open for any given load, high steam economy does not confine to the rated capacity of the machine but is nearly constant over considerable limits.

(3) Ability to affectively utilize extreme steam conditions, i. e. high pressure, super heat and vacuum.

The highest economy is possible only with the expansion through the widest range - from the highest pressure to the highest vacuum, but the vast disproportion of steam volumes at these limits introduces a mechanical difficulty in turbines designed for full peripheral admission. In either case, the small size of the high pressure end of the machine and a comparatively large size of the low pressure end constitute mechanical difficulties before the requisite range of expansion is reached. As previously noted, the partial

peripheral admission of steam permits designing for high pressure, without the use of abnormally short buckets. Therefore, the Curtis turbines can take advantage of practically the highest pressures commercially available. The turbine is also adapted to the use of super-heated steam, and the valves, as well as the body of the turbine, are mechanically constructed with special reference to the prevention of strain or deformation due to wide variations of temperature.

(4) Low cost of supplies, repairs and maintenance.

The amount of oil, waste, etc. is a minimum. Owing to the rugged mechanical design the replacement of parts is seldom necessary.

Reliability:

(1) Simple mechanical construction - large running clearances.

The mechanical construction is simple. The buckets are of the strongest shape and material, firmly attached to the wheel by a heavy dovetail root. The outer ends do not run close to the casing, with consequent danger of contact and blade stripping, but are free and clear. The possibility of interruptions of service due to bucket trouble is exceedingly remote.

(2) Short shaft - disc type wheels.

The fact that there are comparatively few rows of buckets, makes possible a short shaft and short span between

bearings. This greatly reduces the liability to sagging of the shaft and consequent vibration.

The simple steel disc forming the wheels are better adapted to resist centrifugal strain and form a more homogeneous, smooth running rotor than any other construction.

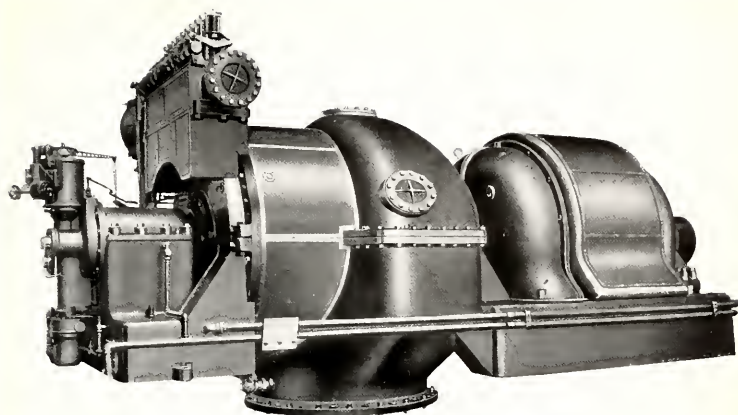
(3) Proper proportioning of turbine and generator to each other.

The steam and electric elements of the set are designed and built in the same shops, and are each correctly proportioned to form a perfect mechanical unit. The stationery parts of each are in many sizes rigidly connected and form practically a solid structure, while the revolving elements are designed as a single rotor.

(4) Absence of distortion due to sudden changes in internal temperature.

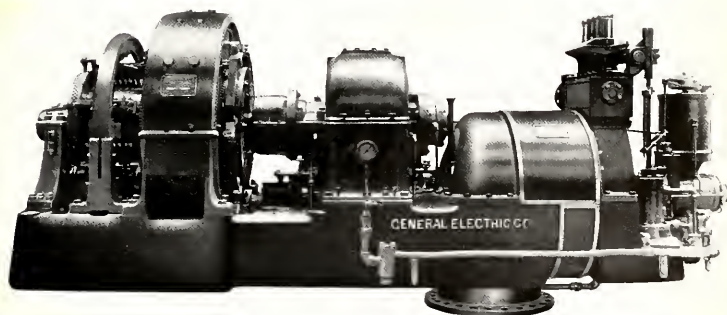
Variations in super heat, shifting in load, or loss of Vacuum, may cause sudden changes in internal temperature, resulting in uneven contraction or expansion. The affect is to distort the casing or supports, and throw the machine out of line, tending to cause contact between the rotor and stator. Curtis machines can be subjected to great changes in temperature without danger of contact, due to their large running clearances, while the short span between bearings tends to minimize the affect of distortion.

Four turbo-generator units - 3 - 5,000 K W. and 1 - 6,000 K W., are chosen. The choice is influenced mainly by the conditions given by the load curve. Any three



6000 Kw.

Fig. 10



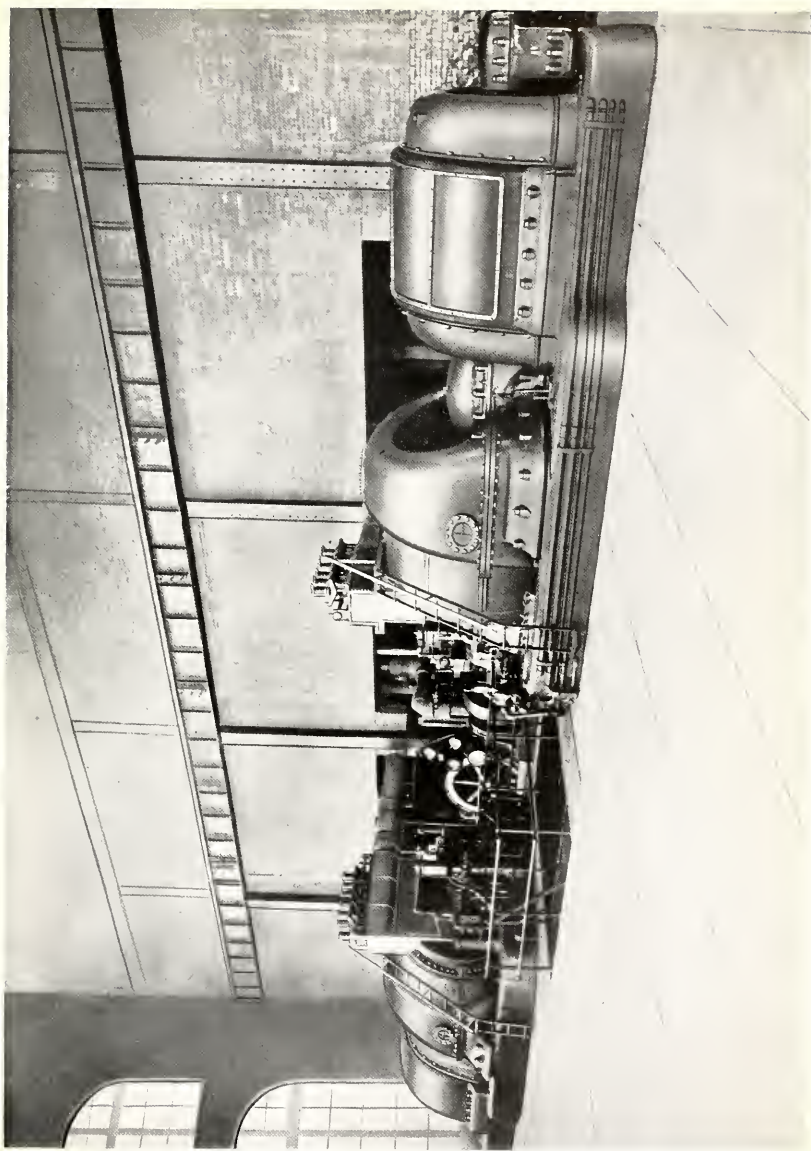


Fig. 11

of the turbo-alternators mentioned can be used to take care of the load and the extra unit can be drafted into use in case of repairs for breakdown or enlargement of the plant, thus insuring continuity of service. Figure 10 shows a 6,000 K W., turbo-alternator unit, and figure 11 shows two 5,000 K W., units installed. A typical steam turbine installation is shown in figure 12.A.

CONDENSERS

The specifications call for the installation of Wheeler surface condensers in this plant.

In surface condensers the steam and circulating water are separated by tubes, and only the condensate is returned to the boiler. Therefore, although under the same conditions the jet may require less water per pound of steam than the surface condenser, the cost of operation is in favor of the surface equipment and often overbalances the lower first cost of the jet outfit. If the auxiliaries are steam driven, as in the plant under consideration, the exhaust is usually used for heating the feed water, thereby reducing the net cost of pumping. Condensed steam from a surface condenser makes the best boiler-feed, being entirely free from scaled-forming matter and containing a considerable amount of heat as compared with cold feed water. In the surface condenser, there is no danger, as in the case of vacuum pumps of a circulating water backing up into the engine cylinder and wrecking the engine. Steam-driven condenser auxiliaries are used in pref-

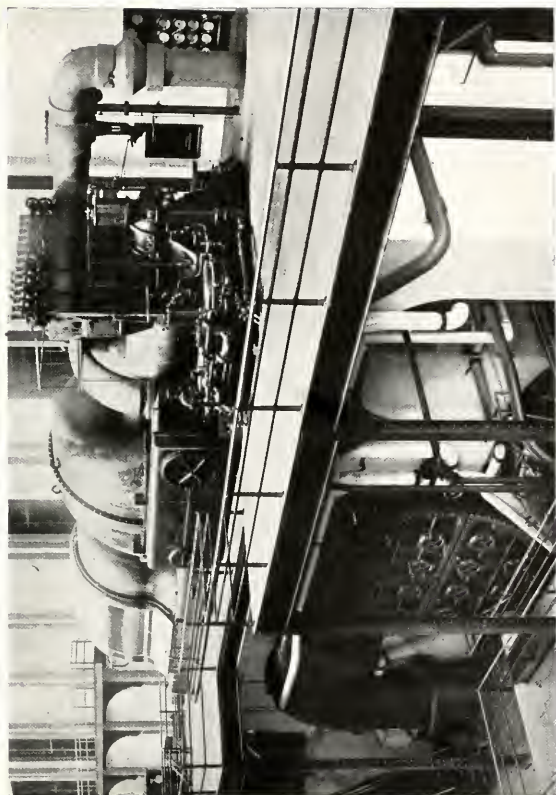


Fig. 12

erence to motor drives because any disturbances on the electrical end will not affect the auxiliaries.

Assume, for purposes of calculation, a water rate of 12 pounds per K W., hour. Total steam per hour equals $12 \times 5,000$ equals 60,000 pounds.

Assume the rise in temperature of the circulating water is thirty degrees Fahrenheit, which is very common.

The weight of circulating water, gallons per minute, Q, equals $1.9 (W \div R)$, where

"W" equals weight of steam per hour

"R" " 30 degrees Fahrenheit.

"Q" " $1.9 (60,000 \div 30)$ equals
3,800 gallons per minute.

This condensing unit, when properly installed and operated, will have a capacity for condensing 60,000 pounds of steam per hour, maintaining in the condenser an absolute pressure of two inches of mercury, supplied with not less than 3,800 gallons of circulating water per minute, at a temperature not exceeding 70 degrees Fahrenheit, all piping connections and turbine being tight and in condition to allow said absolute pressure to be maintained.

The turbo-generators will be operated at full load, maximum capacity being 6,000 K. V. A.

A typical surface condenser installation is shown in figure 12, and figure 13 shows a section view of a surface condenser with pumps.

Three of the above condensing units will be installed.

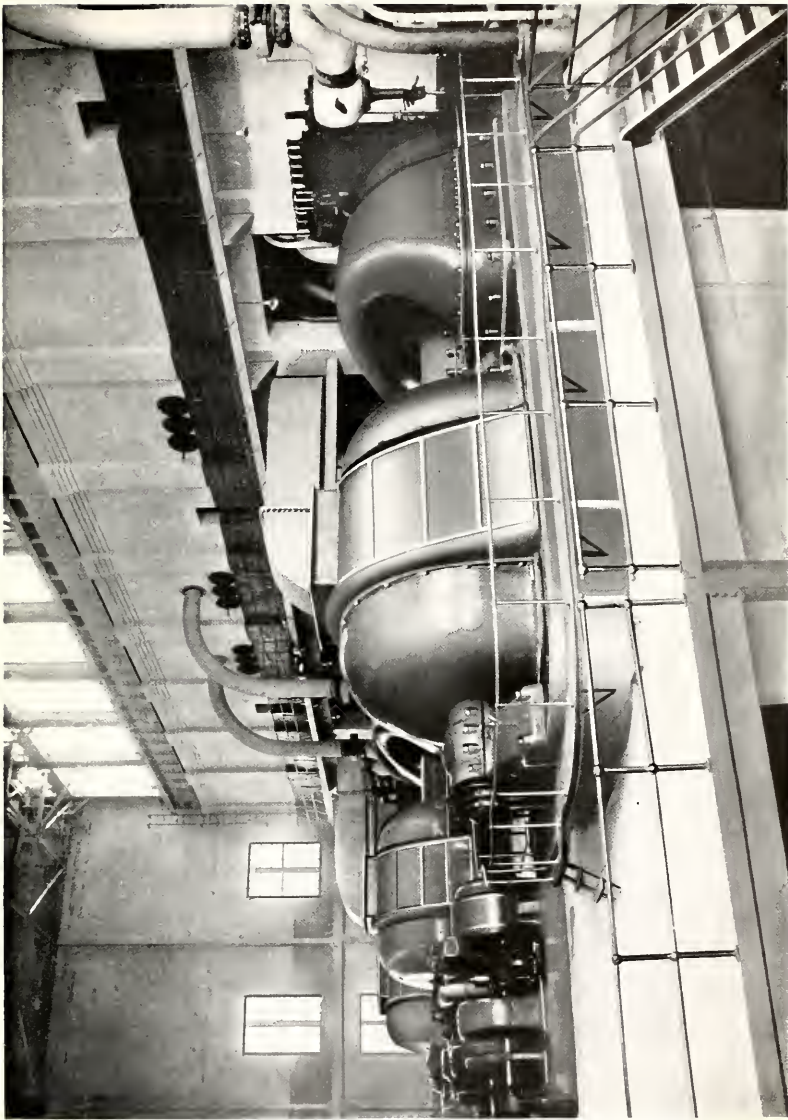
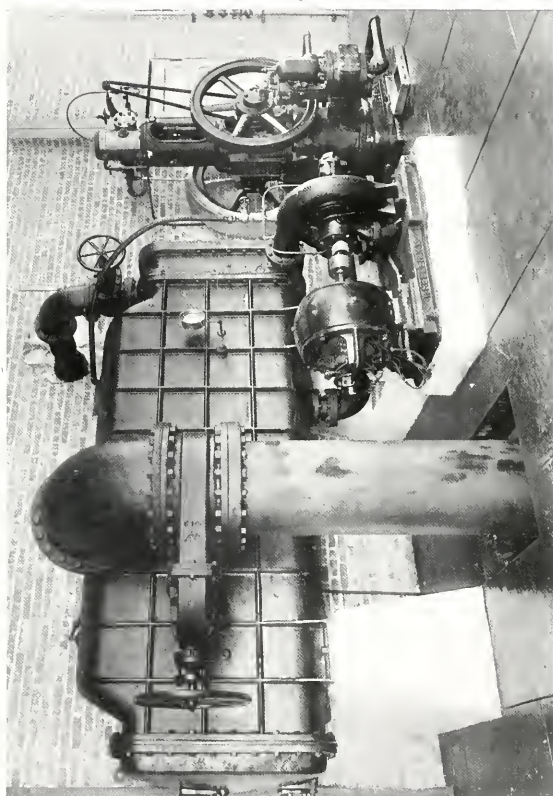


Fig. 12 A



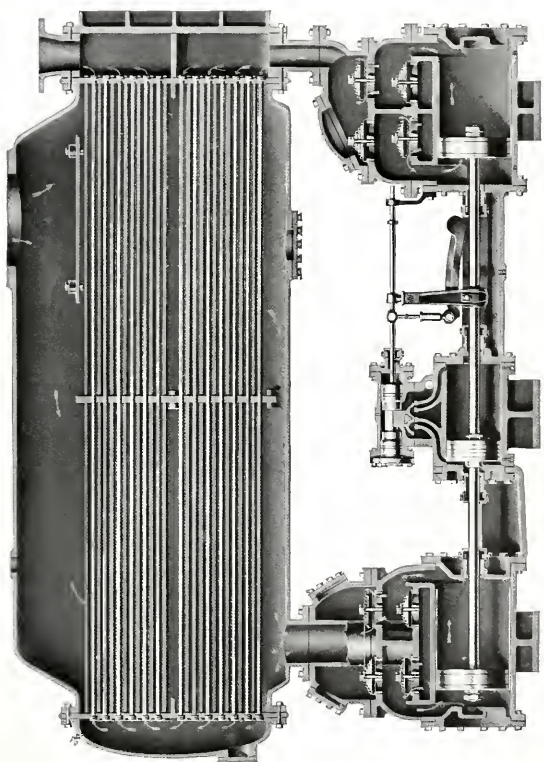
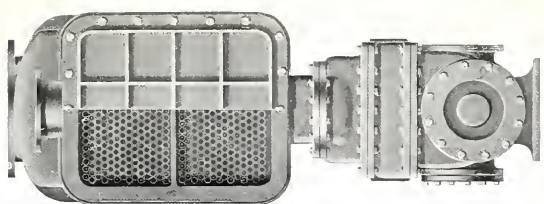


Fig. 13

For 6,000 K W. turbo-generator unit.

Total steam per hour equals $12 \times 6000 = 72,000$ lbs.

Q equals 1.9 (72,000 30) equals 4,560 gallons per minute.

This condensing unit will have a capacity for condensing 72,000 pounds of steam per hour, maintaining in the condenser an absolute pressure of 2 inches of mercury, supplied with not less than 4,560 gallons of circulating water per minute, at a temperature not exceeding 70 degrees Fahrenheit.

One of the above units is installed, making a total of four condensing units.

COOLING WATER PUMPS

Worthington pumps will be used throughout the plant.

The three types of circulating pumps are the centrifugal, the rotary positive displacement, and the reciprocating piston pump. The centrifugal pump is by far the most common in use.

The power required by the circulating pumps is the largest item of the condenser auxiliaries, and, therefore, every effort should be made to reduce the pumping head to a minimum.

The brake horsepower necessary to deliver the circulating water is:

$$\text{Br. H. P. equals } (W \times H) \div (33,000 \times E)$$

W equals weight of circulating water, pounds per minute.

H equals total head, feet.

E equals mechanical efficiency of the pump.

For the 5,000 K W. units:

Assume E equals 70%, which is a common value.

H equals 40 feet.

Br. H. P. equals $60 \times 60,000 \times 40 \div 33,000 \times .7$
 $\times 60$ equals 105.

Where 60 is the ratio of cooling water to condensate. Three of the above pumps are installed.

For 6,000 K W. units:

Br. H. P. equals $60 \times 72,000 \times 40 \div 33,000 \times .7$
 $\times 60$ equals 125. One of the above is used.

A section of a horizontal single suction volute pump is shown in figure 14, and figure 15 shows a sectional view of a centrifugal circulating pump.

VACUUM PUMPS

Worthington horizontal pumps are used.

Dry vacuum pumps are used with surface condensers, where a high degree of vacuum is essential as in steam turbine practice. Such pumps are intended to exhaust the saturated non-condensable vapors only. The volumetric capacity of a dry-air pump for condenser service is based upon experience rather than theory to cause the amount of air in steam and the air infiltration are very uncertain quantities.

The distinctive features of the Worthington rotative dry vacuum pumps are the air valves which consist of a positively actuated slide inlet valve, taking its motion from

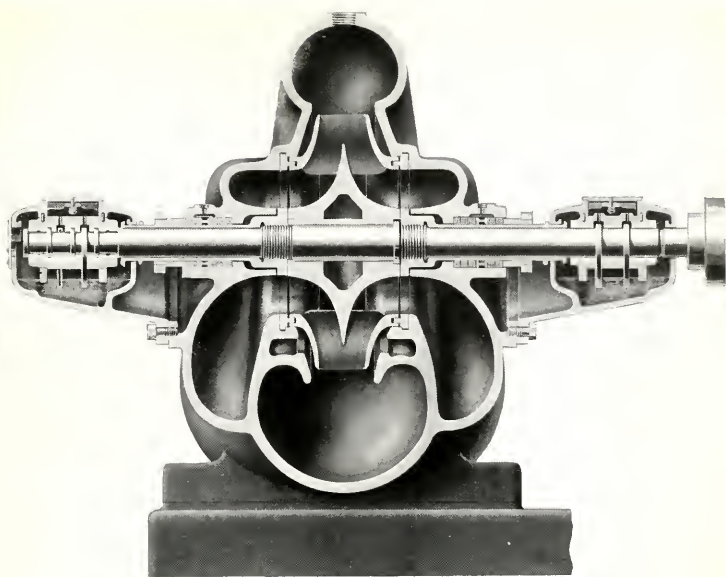


Fig. 15

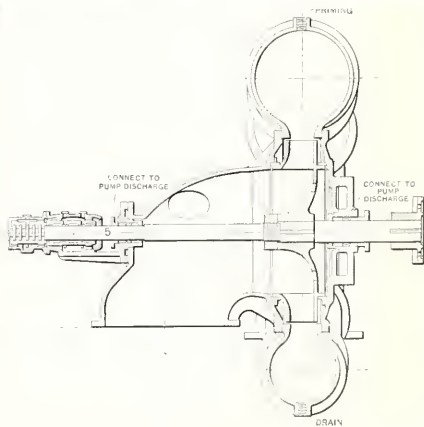
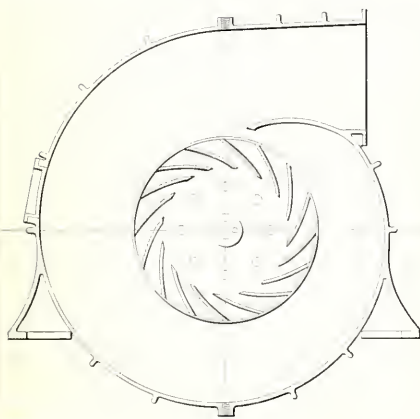


Fig. 14

an eccentric on the driving shaft, and then, spring steel plate, automatically operated, outlet valves, designed particularly for this class of work.. This construction is made up of but few simple parts, requires no adjustment, is not liable to derangement, and needs no repairs. The cylinder and heads are throughly water jacketed. There is no carbonization, and no trouble in lubricating the wearing surfaces. The discharge valves are of the poppet type, and easily accessible. All valves are at the bottom of the cylinder to insure perfect drainage.

For 5,000 K. V. A. units:

Q equals air pump displacement, cu. ft. per hour.

V equals volume of condensate, cu. ft. per hour.

Q equals 50 V.

Q equals $50 \times 60,000 \div 62.5$ equals 48,000

cubic feet per hour. Three of the above units are used.

For 6,000 K. V. A. units:

Q equals $50 \times 72,000 \div 62.5$ equals 57,600

cubic feet per hour. One of the above is used.

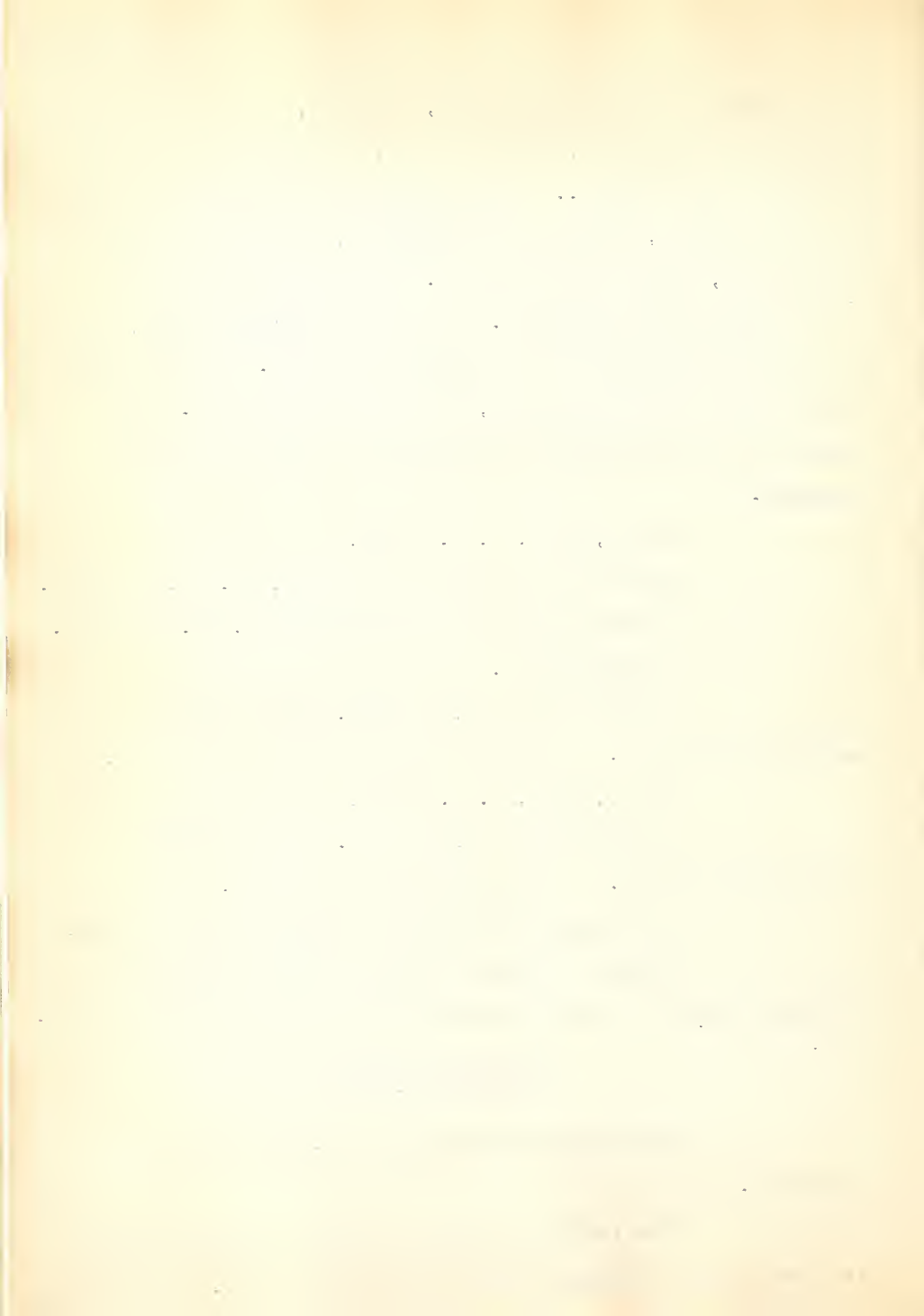
A vacuum of 28 inches of mercury is maintained.

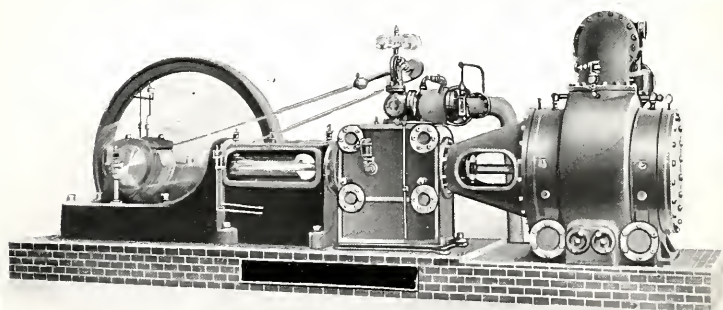
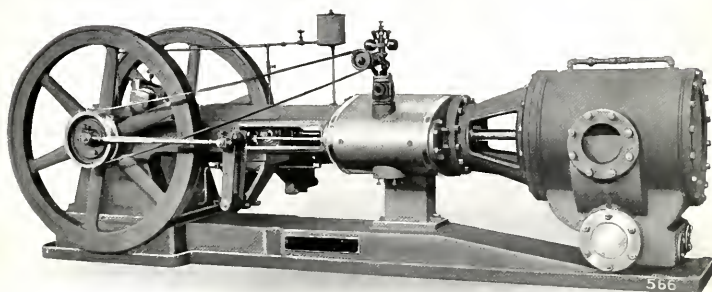
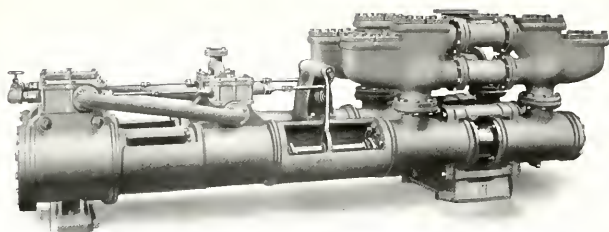
Figures 16 and 17 show the above pumps and a sectional view of a dry air rotative pump is shown in figure 18.

CONDENSATE PUMPS

Worthington centrifugal hot-well pumps are installed.

The centrifugal pump is quite universally used for pumping the condensate from surface condensers. Condensate





Figs. 16, 17, 18.

pumps must deliver water against the head corresponding to the vacuum, plus the friction head and the static head. The pump cannot create a vacuum sufficiently greater than the vacuum in the condenser to draw water into the impeller, by suction, therefore, the condensate should be supplied under a head of three or four feet or more. If the head on the suction side is less than this, the pump will "cavitate" or become vapor bound, and is unable to remove the water. The two stage hot-well centrifugal pump is used in this plant, as it is standard for surface condenser units. These pumps are adjusted to operate at maximum speed, and always deliver against a slight head through a check valve, the condensed steam being automatically delivered as fast as formed without further attention on the part of the employee, and dispensing with all valves, springs, and floats, with their consequent unreliability and frequent unavoidable interruptions of action.

For the 5,000 K. V. A. units:

Suction head corresponding to 28 inches of mercury equal 31 feet.

Assume a friction and discharge head of 29 feet. Assume efficiency equals 50%. The power required to operate the pump equals:

Br. H. P. equals $(60,000 \times (31+29)) \div 60 \times 33,000 \times .5$ equals 4. Three of the above will be installed.

For the 6,000 K. V. A. unit:

Br. H. P. equals $(72,000 \times (31+29)) \div 60 \times 33,000 \times .5$ equals 5. One of the above will be installed.

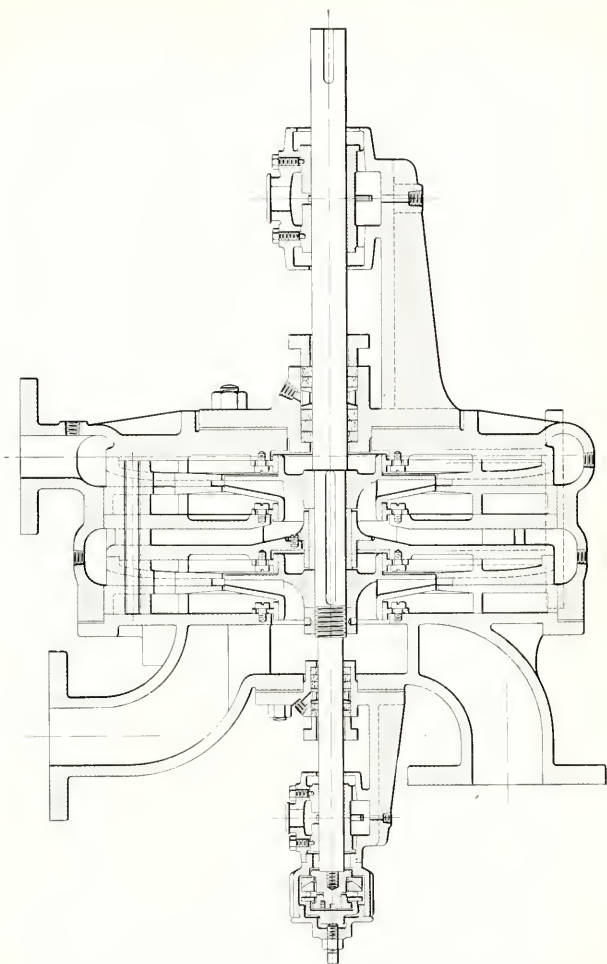


Fig. 19

A section of a two-stage horizontal turbine hot-well pump is shown in figure 19.

Diagram 20 shows the same pump with the turbine driving it, a typical installation.

FEED-WATER HEATER

The open type, Stillwell feed-water heater is used for this plant.

Open heaters are best suited for waters containing scale-forming matters. Much of the temporary hardness may be precipitated in the heater, and the sediment easily removed.

Although a feed-water heater acts to some extent as a purifier, its primary function is that of heating the feed-water. Generally speaking, for every 10 degrees that the feed-water is heated, there is a gain in heat of 1%, and a corresponding saving of coal, if the heat which warms the feed-water would otherwise be wasted. Again, the smaller the distance in temperature between the steam and the feed-water, the less will be the strain on the boiler shell, due to unequal expansion and contraction, an item of no small consequence.

Besides the saving in fuel affected by the use of feed-water heaters, other advantages are secured. The time required for the conversion of water into steam is diminished, and the steam capacity of the boiler thereby increased. Further, the feeding of cold water into a boiler has a tendency toward the setting up of strains due to temperature, which are diminished

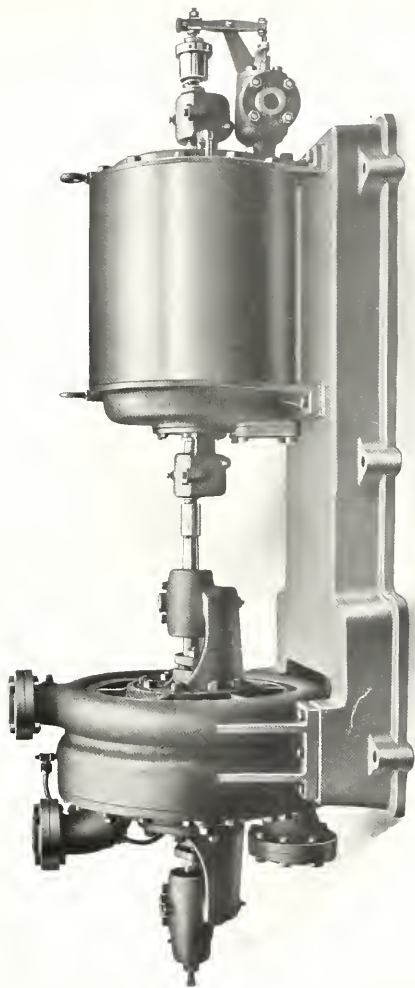


Fig. 20



in proportion as the temperature of the feed-water approaches that of the steam. An important advantage of the open type of feed-water heater is that a large portion of the scale-forming ingredients are precipitated before entering the boiler, with a consequent saving in cleaning and losses through decreased efficiency and capacity.

The heater is of sufficient capacity to take care of the total 5,000 B. H. P. The initial temperature of the water is 70 degrees Fahrenheit and the final temperature is 200 degrees Fahrenheit, before it is introduced into the boiler. This gives a saving of approximately 12% in the fuel supply, with the boilers operating at a gauge pressure of 180 pounds.

Pans containing 2.5 square feet or less are usually made round, and larger sizes rectangular in plan. It is better to have not more than six pans in any one tier, since it is advisable to proportion the pans so as to obtain as low a velocity over each as practicable.

Distance between trays or pans is seldom less than one-fourth the diameter for round pans. Volume of storage and settling chamber in vertical heaters represents respectively 0.4 and 0.6, the volume of the shell with clear and muddy water. Filters occupy from 15% to 20% of the volume of the shell in the vertical type, the smaller percentage corresponding to clear water and the larger to muddy water or water containing a considerable quantity of impurities.

BOILER FEED PUMPS

Where economy of operation is the first consideration, or where the size of the plant makes it desirable, compound steam cylinders are employed. This type of pump, uses about 30% less steam than the simple type when performing the same work. It is usually advantageous to arrange to turn the exhaust from the feed pump into an auxiliary feed-water heater, as in this plant, thus saving nearly all the heat of the steam. Every ten degrees additional temperature of the water entering the boiler means 1% saving in coal.

For 4,500 B. H. P., the dimensions of the pumps are as follows:

Diameter of steam cylinders equals	12	inches
Diameter of water plungers	" 10	"
Length of stroke	" 15	"
Gallons per minute	" 817.	

The approximate space occupied, is - length 15 feet 6 inches, by width 3 feet 11 inches.

Diameter of steam pipe equals	2½	inches
Diameter of exhaust pipe	" 3½	"
Diameter of delivery pipe	" 7	"
Diameter of suction pipe	" 8	"

Two of the above specified Worthington compound pot valve boiler feed pumps will be used. Two pumps are used so that both hot and cold water can be pumped at the same time, hot for feed water and cold for flushing out the boilers, either pump used for either service.

EXCITERS - STEAM TURBINE AND ELECTRICALLY DRIVEN

Two exciters are used, made by the General Electric Co., one steam driven and the other driven by an induction motor.

Allowing 5% of full load for field excitation we get $15,500 \times .05$ equals 750 K. W. Two 500 K. W. exciters will be used, allowing an exciting current of 4,000 amperes, or a total power of 1,000 K. W. One of the above units may be worked at an overload. For peak loads the two in parallel can be used and if one breaks down, the other, with the storage battery, will supply the excitation. One of the 500 K. W. exciters can take care of the average load.

SMOKE STACKS

Two steel stacks are used, one for six boilers and one for four.

For the six boilers, 3,000 B. H. P., the stack will be 96 inches in diameter and 300 feet high, having an area of 56.75 square feet. For the four boilers, 2,000 B. H. P., the stack will be 84 inches in diameter and 225 feet high, having an area of 38.48 square feet. The above sizes are calculated for a consumption of 5 pounds of coal for B. H. P., and sizes are taken from table "57" of Gebhardt's Steam Power Plant Engineering, page 298. The heights mentioned are above the grate.

MAINS AND HEADERS, INCLUDING ALL PIPES
AND INTAKE AND DELIVERY TUNNELS

All piping and fittings are standard and are furnished with the boiler, turbine, condenser, and pump equipment. All bends are long and gradual, and no right angle bends are to be used.

The delivery and intake tunnels are 12 feet in diameter, which is ample for the amount of cooling water and also for eliminating back pressure in the exhaust.

PART 3

ELECTRICAL EQUIPMENT OF MAIN STATION

Alternators:

For capacities refer to the article on turbines. All alternator units are manufactured by the General Electric Co. and are specified as part of the turbo-alternator units. The alternators are designed as part of the set, and the turbines and alternators thus form a unit. The advantages of this arrangement are obvious and need not be dwelt on in detail. This choice insures uniform equipment, and one set of repair parts may be used on any of the units. All equipment must conform to the standardization rules of the A. I. E. E.

SWITCHES

All switches installed are manufactured by the General Electric Co.

Twenty-seven low tension oil switches, 6,600

volts, 15,500 K. W. are installed, 6,600 volts being the generated voltage, and 15,500 K. W. the total capacity. Both "K" and "H" type switches are used. These are shown in the wiring diagram.

Nine high tension 50,000 volt - 15,500 K. W. oil switches are used, 50,000 being the high tension voltage. These switches are also shown in the wiring diagram.

Disconnects are installed so as to completely disconnect or isolate any particular piece of apparatus so that repair or replacement work can be safely done on it.

TRANSFORMERS

Three single phase transformers are to be used in connection with each alternator unit. They are connected Delta-delta, (see wiring diagram of main plant). The transformers are oil cooled and capable of standing a 50% overload for, at least, two hours without excessive overheating. Each of the transformers used with the 5,000 K. W. units is to have a capacity of 1,675 K. V. A. normal rating. The three used with the 6,000 K. W. machine will have a capacity of 2,000 K. V. A. each. All transformers are 6,600 - 50,000 V.

PROTECTIVE EQUIPMENT

One set of 80,000 volt aluminum cell lightning arresters is to be supplied for each feeder. The line voltage is 50,000 volts and the peak value, assuming a sine wave of voltage, will be 50,000 ($2\frac{1}{2}$) equals 70,700 volts. To prevent

a continuous discharge to ground, 80,000 volt arresters will be used, and the horn gaps set to break down at this voltage. The necessary choke coils are to be supplied with the arrester sets.

Bus insulators must be supplied capable of withstanding a voltage of 70,000 volts for the high tension equipment, and 10,000 volts for the low tension equipment.

All electrical equipment, wherever possible, and in accordance with common practice is protected by the use of the Mertz-Price system.

SWITCHBOARD

The switchboard is shown in detail in the switchboard diagram included in this thesis. The wiring of the main board is shown in the wiring diagram of the main station.

All switching is done by remote control (except in the substation) and pilot lights show when a switch is open or closed.

All necessary meters are installed in plain view of the operator.

All switches, disconnects, protective devices, switchboard panels, pilot lights, etc. will be General Electric, standard equipment.

PART 4DIRECT CURRENT SUBSTATION EQUIPMENT

It is not the purpose of this thesis to go deeply into the design of D. C. railway substations, as this would, in itself, make a work of considerable magnitude. It is, however, our intention to choose the apparatus and lay out the substation in the best way possible as regards economy, efficiency, and the best engineering usage under the given conditions.

The substation is to furnish direct current for railway power in the immediate vicinity of the plant, other substations, both automatic and manually operated, being situated along the line of the road as the conditions demand.

The station, as designed, has a full load rating of 2,000 K. W. Two machines of the same characteristics are used, each having a full load rating of 1,000 K. W., and capable of carrying a 50% overload, making 1,500 K. W. for each machine or a total safe output of 3,000 K. W. Machines of the above rating were chosen with the understanding that the maximum direct current load would be not greater than 1,500 K. W. at this point of the line, thus making it possible to run both machines at 75% load, or one machine at 150% load. In case of accident to one machine or its auxiliaries, the other machine could carry the load. Running both machines at 75% load would give a fairly high operating efficiency and one machine would not be idle.

In determining the type and size of apparatus for railway substations, it is of material advantage to select

standard apparatus insofar as the requirements of the installation will permit. The obvious advantages of this practice are low initial cost, prompt delivery, apparatus designs perfected by usage and of proven reliability.

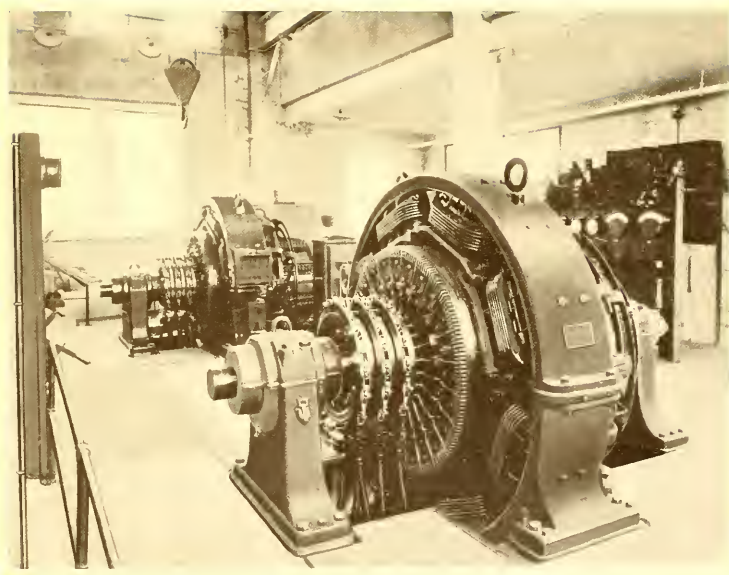
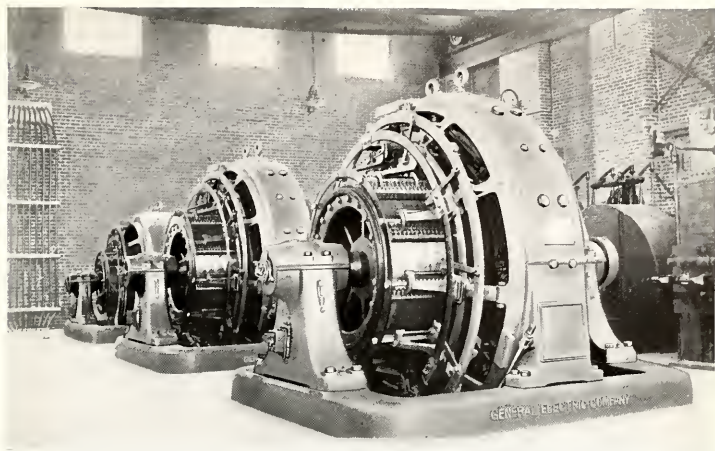
The apparatus for the station in order from the supply current is as follows:

- (a) High tension oil switches
- (b) Step down transformers
- (c) Regulating reactances
- (d) Synchronous converters
- (e) Switchboard, including A. C. control switches (remote control), D. C. control switches and protection devices, feeder switches and circuit breakers.
- (f) Lightning arrester, outlet bushings, etc.

ROTARY CONVERTERS

As mentioned above, two rotary converters of identical specifications (the characteristics being alike for satisfactory parallel operation) are used in the station. They are of the 25 cycle, 6 phase, commutating pole, compound wound type. The 6 phase voltage is obtained from the 3 phase circuit by means of a simple diametrical connection. (See wiring diagram of substation).

Due to improved design, it is possible to employ units of lower normal rating than formerly because of the high overload capacity of the converters, thus improving the load



factor, power factor and efficiency. By making the continuous rating of the units more nearly equal to the average load value of the substation, it is possible to operate at maximum efficiency, and thereby improve the all day efficiency of the substation. Smaller units require less floor space and have a corresponding reduction in cost. Where unusual conditions of operation are not encountered, consideration of economy, efficiency and maintenance distate a selection of synchronous converters over other types of converters for 25 cycle work.

Twenty-five cycle machines were chosen because of the two following reasons:

(a) The frequency of the generated power is 25 cycles.

(b) Much greater satisfaction is obtained with the use of the 25 cycle machine than with the 60 cycle machine, although the 60 cycle type is growing in popularity. Flash-overs are common occurrences with the 60 cycle in spite of great care taken by the operator. The speed of this machine is obviously higher than that of the 25 cycle machine having the same number of poles.

The machine is compounded to make the D. C. voltage practically the same at full load as at no load. This regulation is affected by the use of inherent reactance in the transformers, and assumes a constant A. C. voltage at the primary of the transformers. The reactances in the A. C. leads to the machine are used to adjust the A. C. voltage and to assist in taking care of surges in the line. The only way to regulate the D. C. voltage is to regulate the A. C. voltage. The D. C.

voltage is a function of the A. C. voltage. Increasing the field strength increases the A. C. armature reaction and the two are very nearly equal and therefore neutralize each other.

Two type H. C. C. General Electric converters were chosen. These machines have the following specifications:

Poles --- 6
K. W. --- 1,000
R. P. M. --- 500
Length --- 108 inches
Width --- 77 inches
Height --- 76 inches
Net Weight --- 29,000 pounds
Armature and Shaft Weight --- 9,300 pounds
Voltage --- 430 - 600
Frequency --- 25 Cycles

These machines comply with the A. I. E. E. standards as to maximum temperature rise, voltage break-down, etc.

OIL SWITCHES - HIGH TENSION

The oil switches used are of the "K" type, the solenoid operating coil being controlled at the substation switchboard A. C. panel. These switches are situated on the wall of the generating station of the turbine room, just beneath the switch gallery. These switches are marked "C" on the plan view.

The switches are of the same type and rating as the other "K" type low tension switches being of 15,500 K. W. - 6,600 volt capacity. General Electric switches are specified for this installation.

TRANSFORMERS

In choosing the transformers, there are several things to be considered. The most important of these are:

- (a) Ground space available.
- (b) Type of transformer best adapted to the kind of service required.
- (c) Method of cooling transformers.
- (d) First cost.
- (e) Cost of repairs - Maintenance.
- (f) Continuity of service.
- (g) Extra units for emergency purposes.

There are two general types of transformers on the market for this type of service, namely, the three phase transformer or the bank of three single-phase transformers. Both systems have their advantages and disadvantages over the other. After a study of these conditions, the authors decided that in the case in hand the disadvantages encountered with the use of poly-phase transformers more than offset the disadvantages encountered with the single-phase method.

The selection of any particular type of transformer is largely a question of local conditions, as all types are equally reliable and have practically the same efficiency. Modern practice seems to favor the type "H", self-cooled transformer. See Figure 21. These units require no auxiliaries.



TYPE H TRANSFORMER EQUIPPED WITH
STIFF LEADS

Fig. 21

General Electric, 350 K. V. A., H. R., 25 cycle, 6,600 - 430 volt transformers were chosen. These transformers are connected Delta-Delta. With this connection two transformers will continue to carry the load on open Delta. The size of the load that it is possible for the two transformers to carry with the same heating as in the closed Delta connection is, however, cut to 57.7% of the load carried by the three transformers in the closed delta. This amounts to $3 \text{ (350)} \cdot 577$ equals 605.85 K. V. A. This is, in some ways, a disadvantage, but it will help to keep the service continuous in case of break down of one transformer. From what has been said, it will be seen that there is a double protection against failure of the station to supply the railway power:

(a) Two machines are available, one being used in case of emergency.

(b) The open Delta connection, so that a machine can deliver at least 57.7% of its load in case of a break-down of one transformer.

In case of the complete break down of one unit, the other unit could take care of the maximum load for more than two hours. This is ample as the peak loads for railway work are seldom on for that length of time. A small repair to the damaged unit could be made in two hours.

Proof that one unit could carry the peak load for two hours or more:

One 1,000 K. W. machine operated at 50% overload will give 1500 K. W., the assumed maximum. This will be possible

for longer than the two hours required with the modern, highly developed machine. One 350 K. V. A. transformer will run at 150% load for two hours without exceeding a temperature rise of 60 degrees Centigrade. The normal load continuous rating is based on 40 degree Centigrade rise for oil cooled transformers.

350 x 1.50 x 3 equals 1,575 K. V. A.

The transformers and the machine are, therefore, capable of supplying the maximum load during the peak period. During this time repairs would be made on the damaged unit.

The alternating current voltage between rings of a converter in terms of the D. C. voltage is given by the equation

$$E_n \text{ equals } (E_0 \div \sqrt{2}) \sin \frac{\pi}{n} \quad \text{where}$$

E_n equals Voltage between rings A. C.

E_0 equals D. C. voltage

n equals number of rings.

Then for a D. C. voltage of 600 volts and a 6 phase (6 ring) converter, the A. C. voltage must equal

E_n equals $(600 \div \sqrt{2}) \sin \pi \div 6$ equals .354 (600) equals 212.4 volts. The 3 phase voltage equals 424 volts. Standard transformers are wound for 430 volts.

SWITCHBOARD EQUIPMENT

The switchboard consists of two A. C. control panels, two D. C. control panels, and eight feeder panels. The board is arranged in the following manner, starting from either end:

Four D. C. feeder panels, one A. C. panel, two D. C. panels, one A. C. panel, and four D. C. feeder panels. Many designers prefer to group the feeders, the A. C. panels and the D. C. converter panels together, but in this case it was thought best to keep each unit control separate, and to give the board a symmetrical appearance by placing half the feeders on each end. This method also adds to the ease in operating the station.

Switchboard panels for D. C. railway substations are designed for maximum simplicity, convenience and reliability. Only the positive bus is brought to the panel, thus reducing the danger of short circuit between opposite polarities.

The main converter panels for 600 volt direct current are 16 inches in width, $1\frac{1}{2}$ inches thick, and have a total height of 90 inches, divided into 3 sections, as follows:

Bottom panel --- 28 inches
Middle panel --- 31 inches
Top panel --- 31 inches

The material used is a natural dull black oiled slate. All instruments are calibrated to read the overload capacity of their respective machines, and the switches, circuit breakers, etc. will carry 150% of the normal rating of the machine continuously. The panels are supported on pipe frame-work, with suitable attachments for the support of bus bars, rheostats, etc.

The A. C. converter panel equipment consists of the remote control switches for the oil switch, the pilot lamps for this remote control switch, A. C. volt meter, and instrument transformers.

The D. C. converter panel includes:

- (1) Carbon break circuit breaker.
- (2) Ammeter and ammeter shunt.
- (3) Two point potential receptacle.
- (4) Field rheostat mechanism.
- (5) Single pole main switch -- quick break type.
- (6) Watthour meter.

The D. C. feeder panel is equipped with a carbon-break circuit breaker, an ammeter (optional), a single pole main switch, and a two point potential receptacle (optional).

A pit is provided at the back of the board to carry leads, buses etc.

A bell alarm is included in both the converter circuits and the feeder circuits to warn the operator when a circuit breaker opens up. This circuit can be clearly seen on the substation wiring diagram included in this thesis.

A voltmeter, power factor meter, and synchroscope are mounted on a swinging bracket at the left end of the board (from the front).

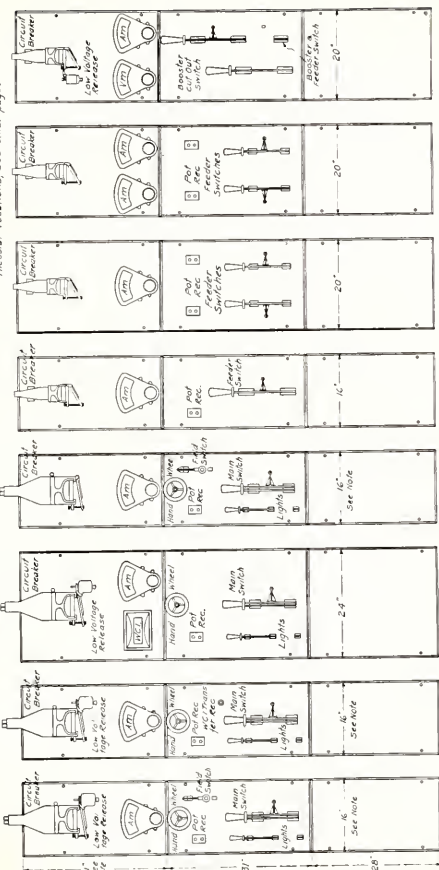
A complete wiring diagram of the substation is included in this thesis.

Some typical D. C. panels are shown in fig.22.

MISCELLANEOUS

Both converters are equipped with a speed limiting device for protection against excessive armature speed in case of failure of the A. C. circuit and the shunt field circuit. Magnetic oscillators are specified as part of the standard equipment. A brush raising mechanism is to be provided to raise

Panels are Natural Black Steel, $\frac{1}{8}$ " thick with "A" level except those above Jawsamp panel rating, which are 2" thick. For end views of panels and
 for locations of panels see other pages.



OUTLINES OF STANDARD 600-VOLT D-C. SWITCHBOARD PANELS

Fig. 22

the brushes from the commutator to prevent sparking when the machine is started as an induction motor. The correct polarity can be obtained when the other machine is running, by throwing in the equalizer switches. The polarity is indicated by means of the two small narrow brushes that remain on the commutator to supply the excitation when the machine is being started. A converter started from the A. C. side does not require to be synchronized.

Lightning arresters are required for protection to both A. C. and D. C. apparatus. In this particular case the A. C. arrester may be eliminated due to the fact that the A. C. line is confined within the station. The D. C. side, however, must be protected because disturbances may occur on the feeders.

There are two general types of D.C. arresters in use, namely, the aluminum cell arrester and the magnetic blowout arrester. While the aluminum cell arrester gives the best protection obtainable, it requires inspection and attention at regular intervals to keep it in good operating condition. It is also somewhat more expensive than other types. For average conditions the magnetic blowout type is sometimes used where the expense of the aluminum cell is not justified.

For the best protection of the D. C. apparatus one direct current aluminum cell arrester should be used on each outgoing line but in this design it is proposed to have feeder arresters at several points along the line. In view of this fact it is thought best to provide the converters with aluminum cell in spite of their greater expense, as the increased protection is desired if there is to be no arrester on each feeder in the station.

For the protection of the converters against flashovers caused by potential surges, the D. C. aluminum arresters should be connected directly across the armature bus rings, inside the series field.

Ample ventilation is assured the substation as it is situated in a large room that is properly ventilated.

Porcelain wall bushings are used for the outlet of feeders that go to overhead lines. As the voltage is low these bushings may be of any good type. Protection from weather must be had, this being accomplished by means of a protecting hood. This hood extends out from the wall 18 inches and prevents rain and snow from entering the station through the wall outlets.

PART 5

Description of Building and Layout of Apparatus.

The building occupies a ground space of 32,530 square feet. In addition to this, a yard for coal storage etc., of about 10,000 square feet should be allowed.

For convenience in the description of the layout of the building we will consider the top of the plan view as north (N), the right as east (E), the left as west (W), and the bottom as south (S).

The building, which is 167'8" (N x S) by 194' (E x W), outside to outside, may be divided into three general sections, namely, the boiler room, the turbine and engine room, and the switching room. Each of these rooms or sections may be greatly subdivided and will be treated separately later on.

The walls are made of common baked building brick being of such a thickness that a factor of safety of 6 is

assured. The outside layer is of red brick and a suitable design in stone forms a border around the top. The floors and foundations are of concrete heavily reinforced. All walls are designed so that a factor of safety of "6" is assured while the floors are designed to give a factor of safety of "10".

The south, east, and west, walls are 1'9" thick this being ample for the support of the roof and the floors with the weight of the different apparatus. The north wall is somewhat smaller being 1'6" thick as this wall does not carry as large a load as the other ones. The walls are supported at regular intervals by "I" beams. Windows are provided wherever possible so that ventilation and light are well provided for. Strength, however, was not sacrificed for air and light.

The walls on the north and south sides of the turbine room are 1'6" thick but the I beam supports are large enough to support the "Toledo" crane and a load of 40 tons. Brackets are used on which the crane track is laid.

The partition which incloses the office is 6" thick. This wall supports only its own weight. A suitable deadening is provided in the partition so that the office is sound proof.

Fink trusses were chosen for the roof over the boiler and turbine rooms so that the necessary strength could be obtained without the use of posts or beams in the center of the room. The roof over the switch room is flat because the necessary strength can be obtained without using center supports. This roof tapers to provide for the drainage of rain and snow.



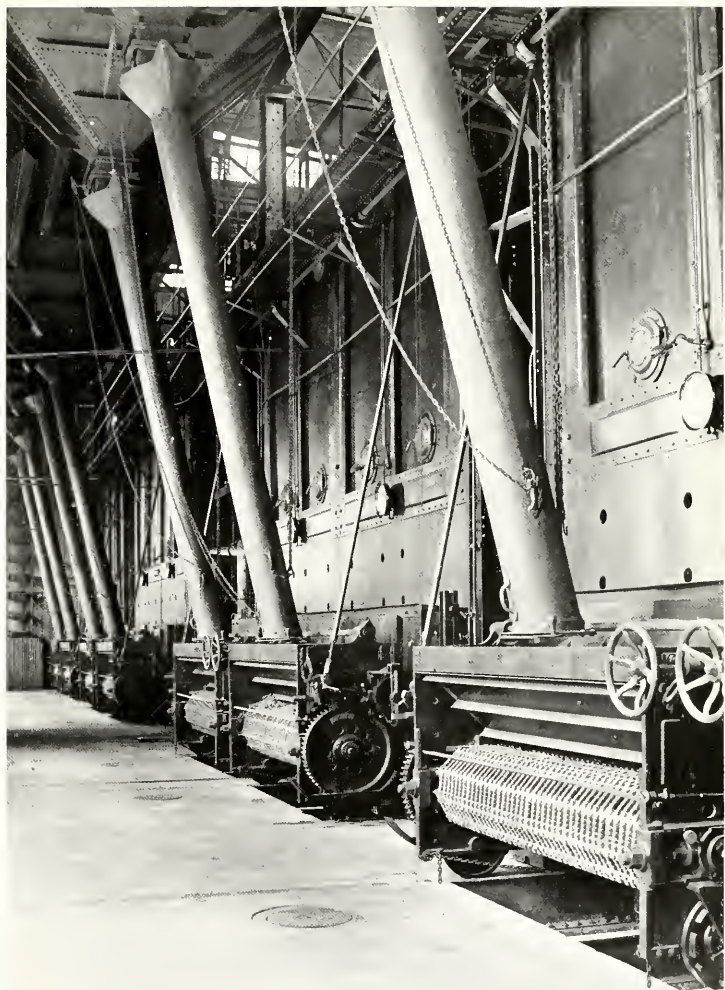
BOILER ROOM

The boiler room is 171'3" by 66' giving a floor space of 11,302½ square feet. This room is on the south end of the building.

The one bank of 5,000 H. P. arranged in banks or batteries of two boilers of 500 H. P. each, extends along the full length of the room with the grates to the south. (See plan). The batteries are placed 6' from each other and a clearance of 6' is allowed at the east and west walls. The from the south wall is 14' this being sufficient for the removal of the tubes for repair. The distance from the rear of the boilers to the north boiler room wall is 25'. The batteries, including the grate space occupy a floor space 27'x 27'.

In the basement, below the boilers, are the ash bunkers, one for each boiler. A special coal valve is provided so that the ashes and fine coal may be taken away at a certain time without interfering with the conveying of coal to the bunkers.

A standard gauge track is installed to the east of the boiler room (see plan view), and runs into the turbine room. A bunker, under the track and in line with the ash bunkers, leads to the coal crushers. Coal is dumped into this bunker from the coal cars. The conveyor runs under the crusher, up the east side of the building, over the coal bunkers, down the west side of the building, under the ash hoppers and so on. It is seen then, that the conveyor serves two purposes; it carries crushed coal to the bunkers, and it carries the ashes out to the car that has just unloaded its coal. The track leads into the turbine room so that, by the use of the crane, machinery may be brought in or



shipped out.

The main and auxiliary steam and exhaust headers are hung on roller brackets on the north wall of the room.

The stacks, open air exhaust pipes, and the feed water heater are back of the boilers and placed so that there is plenty of room to work conveniently.

The coal bunkers, above the boilers, extend the full length of the room and are 38' in width.

Doors are placed where necessary so that employees have easy access to the turbine room from the boiler room.

TURBINE ROOM

The turbine room, or rather the machine room, as it might be called, consists of a basement on a level with the basement of the boiler room and 12' below the level of the first floor, and the main or turbine floor. The basement floor and the turbine floor are both the same size being, 190'6" x 64'6". The area of the basement is 12,287½ square feet. The turbine floor is partly cut away for convenience in operating the plant. By having this arrangement the operator can see if the proper auxiliaries are running when a turbine is put on the line, and the engineer in charge can keep a better check on the operation of the rotating machinery. The area of the turbine floor is approximately 9,963 square feet.

On the turbine floor are located the four alternator units, the 2000 K. W. two unit, substation for D. C. railway power, the low tension oil switches, and the two tracks. One of these tracks is standard gauge and leads in from the coal hopper as explained above. The other track is narrow gauge and

is used to transport the transformers from the transformer room to the turbine room so that they can be placed on the freight cars by means of the crane. A 25 ton crane runs the full length of the building.

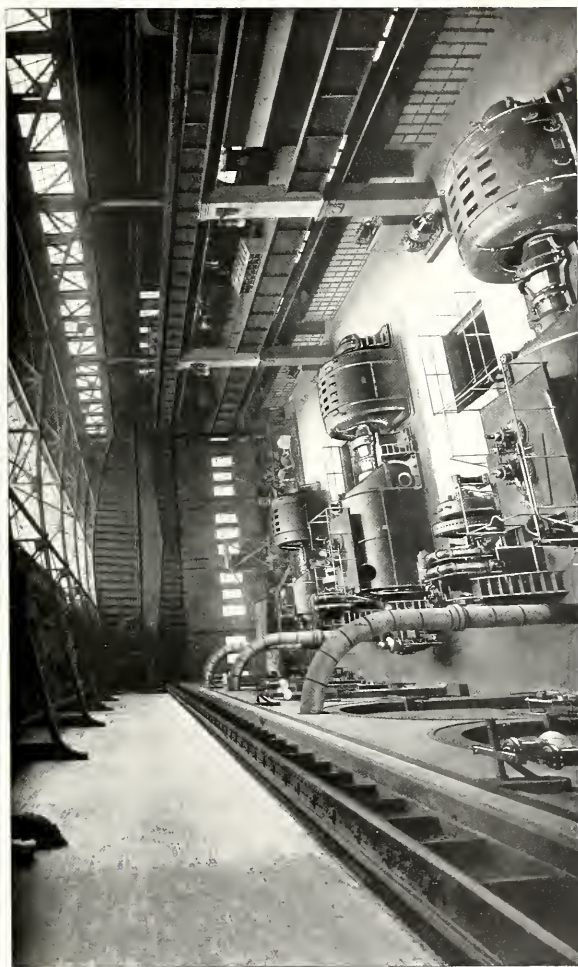
The switch gallery is located partly in the turbine room and partly on the second floor of the switch section. This gallery is one room, the wall between the switch section and the turbine room being cut away at this point. A clear view of the turbine room is afforded the operator from this gallery. In this gallery is located the switchboard, a drawing of which, is included in this thesis.

In the basement are located the condensers, vacuum pumps, condensate pumps, condensate header, steam and electrically driven exciters, feed water pumps and cooling water pumps. The apparatus is arranged in such a way that all moving machinery is in clear view of the operator or engine man on the turbine floor.

Stairs between the basement and the first floor are provided wherever it was thought necessary for the convenience of the employees. A flight of steps leads from the turbine floor to the switch gallery.

Large windows are specified for the ends of this room, as they will afford the only means of daylight illumination. Electric lighting is obtained with the use of a 6,600--220-110 V transformer. Heating in winter is obtained from exhaust steam.

As can be seen in the drawings, space was provided for additional units when an increase in the load warrants such an addition to the present equipment.



Plenty of clearance has been allowed around all the apparatus so that workmen may make repairs quickly. These two rooms were laid out with a view to cleanliness, neatness of arrangement, and to the best engineering practice as to efficiency etc.

SWITCH ROOM

The switch room or section, may be divided into three separate sections. These sections are each located on a separate floor. On the first floor are the transformer room and offices. On the second floor are located the oil switches, switch gallery, and repair rooms and store rooms. On the third floor the lightning arresters are installed and the line towers are mounted on the roof of the second floor just opposite the arresters.

The transformer room is 138'2" x 32'6" and has a floor space of 4,489.1 square feet. The potential transformers are located almost in the center (N X S) of the room and run, in banks of three, along the length of the room. The current transformers used in connection with the high tension measurements are located about four or five feet behind, and are lined up with, the potential transformers. These current transformers are mounted on frames so that their terminals are on a level with those of the static transformers.

The low tension buses, instrument transformers, and lead pot heads are mounted on slate protected panels on the south wall of the room. The high tension buses are suspended from the second floor and are separated by slate protectors or panels.

The office, which is on the first floor, is located in the north east corner of the building. The room is 50'10 $\frac{1}{2}$ " x 32'6". This is divided into an outer or general office, a lavatory and locker room, and a private office. The private office is 22'3" x 22'3" and is separated from the main office by a 6" partition. The outer office, if not required for office work, can be used a recreation room for employees. Windows are provided on all four sides of the office, and a door leading outside is provided as well as the doors leading into the plant.

The repair shop and store rooms mentioned above are located directly over the office. In case of the necessity of increasing the office space the second floor could be connected by stairway with the office on the first floor thus doubling the office space.

The space allowed for the lightning arresters is in excess of that required for the four lines specified in the electrical layout. As this holds for the switch room also, it can be seen that an additional number of lines may be installed when necessary. As explained previously, space has been allowed for an additional unit in the turbine room to care for any future additional loading.

PART 6The Design of Transmission Line

The distributing system to be used in this design will consist of four feeders, two of which, are forty miles long, and two sixty miles long. In the calculations we will consider the system as one consisting of two feeders each one hundred miles long.

The required size of conductor is determined by:

- (a) Mechanical strength
- (b) Permissible energy loss
- (c) Required voltage regulation
- (d) Corona
- (e) Cost
- (f) Current-carrying capacity

Mechanical strength is a primary consideration in any transmission line. It becomes especially important where long spans are necessary.

Permissible energy loss is determined by such factors as the cost of generating power, selling price, load-factor, and other economic considerations. Where power is produced cheaply, it may be more economical to lose power in the line than to pay the fixed charges incident to heavier conductors and poles.

Required voltage regulation is, in general, not difficult to secure, as automatic regulators and synchronous apparatus may take care of any voltage fluctuations at the sub-stations. If, however, the inductive line drop for a given cross-section of conductor is too great, two separate lines of half the cross-section may be used. The additional cost of insulators

poles and construction seldom justifies duplicate lines, where better regulation alone is the requirement.

Corona may make the energy loss in excess of the permissible value, in which case, it will be necessary to increase the conductor diameter or the effective size of conductor.

The current-carrying capacity of the conductors under continuous operating conditions, is usually ample when the size of wire is determined by the permissible energy loss. An emergency demand, however, may overload the line for a short time, and where this is likely to occur, the conductor should be of such a size as to operate within safe temperature limits.

CALCULATION OF LINE

15,000K.W. 2 equals 7,750K.W. per line

Assume a line loss of 8%. Therefore the line loss equals

$7,750 \times .08$ equals 620 K.W.

I R equals 620,000 watts

Assume a power factor of .8

I equals $\frac{7,750,000}{.8 \times 50,000 \times 1.732}$ equals 110 amperes

R equals $\frac{620,000}{110 \times 110}$ equals 51 ohms.

R equals $\frac{Kl}{a}$

K for copper wire equals 1.5×10^{-6} ohms per cm.

a equals $\frac{1.5 \times 100 \times 5280 \times 12 \times 2.54}{10^6 \times 51}$ equals .5 cm.²

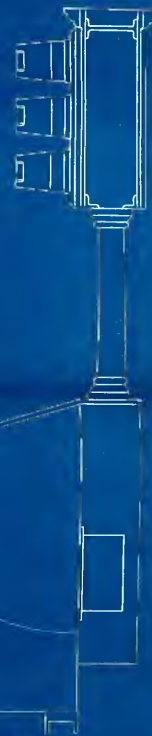
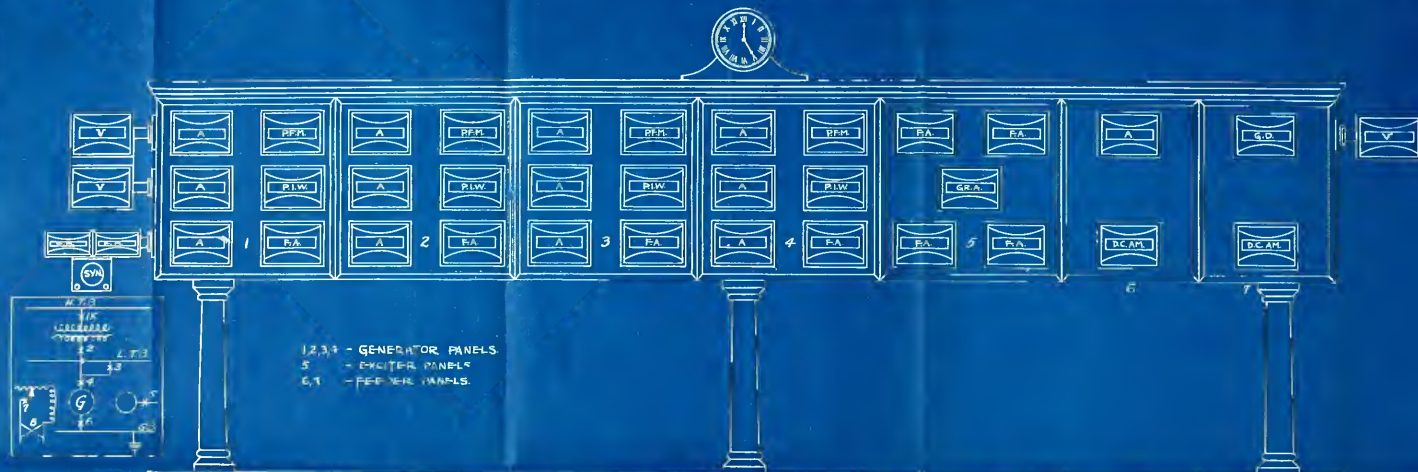
radius equals $(\frac{.5}{\pi})$ equals 0.16 cms.

Use a #6 B. & S. wire gauge wire for this installation.

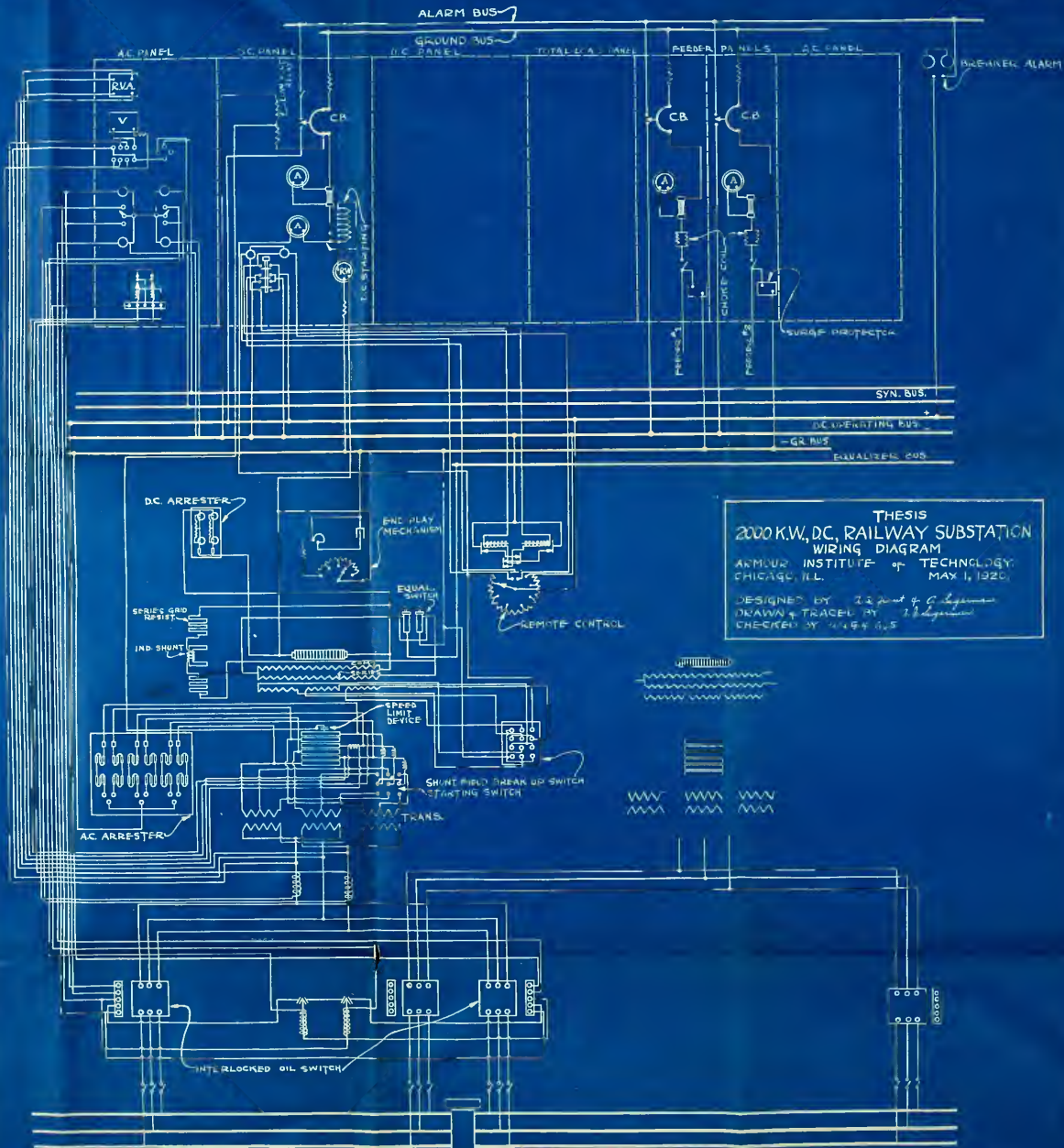
Use a spacing of 5 feet the wires being arranged in the form of a delta. Wooden poles are used for supports and the minimum clearance is to be 18 feet.

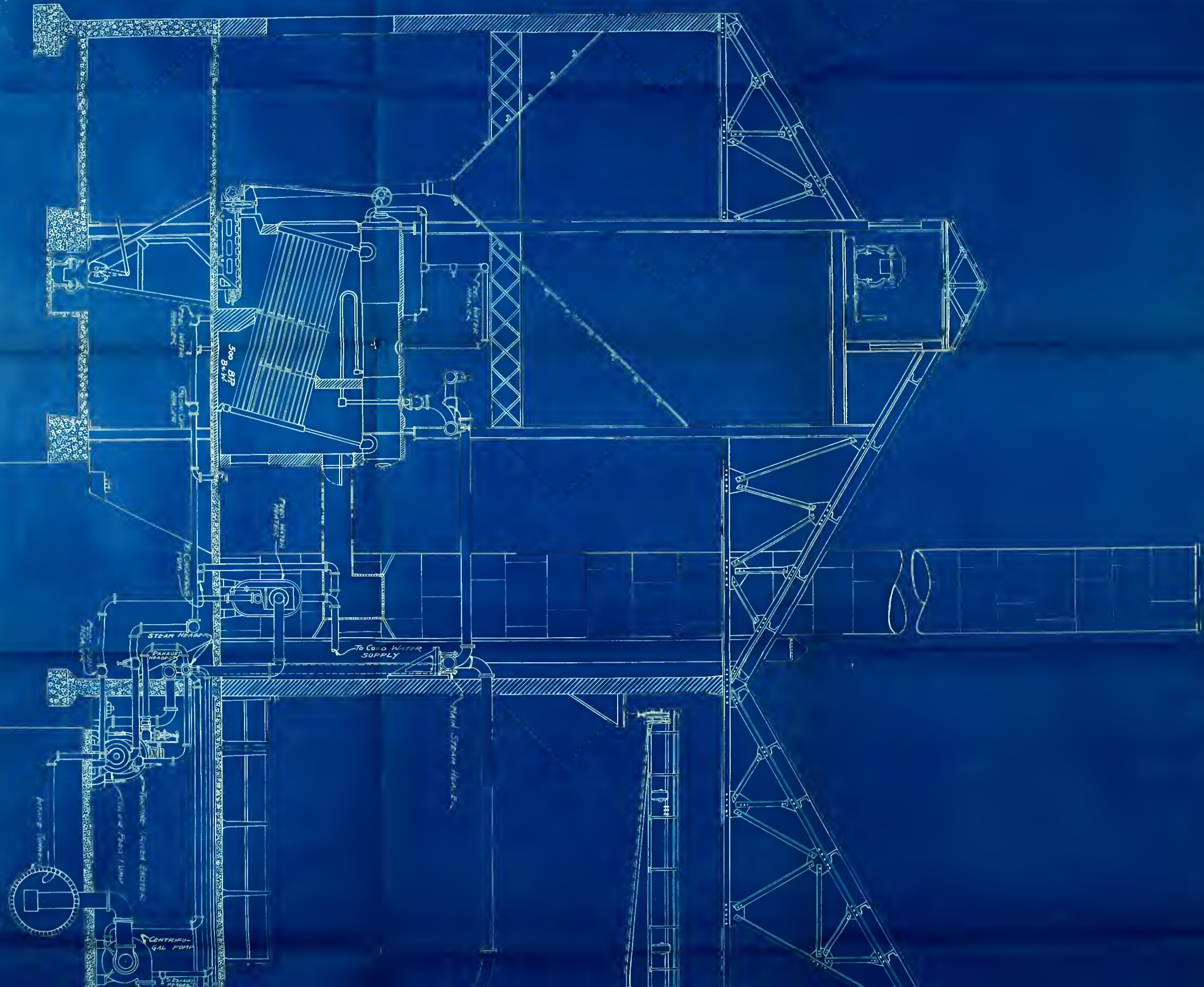
BIBLIOGRAPHY

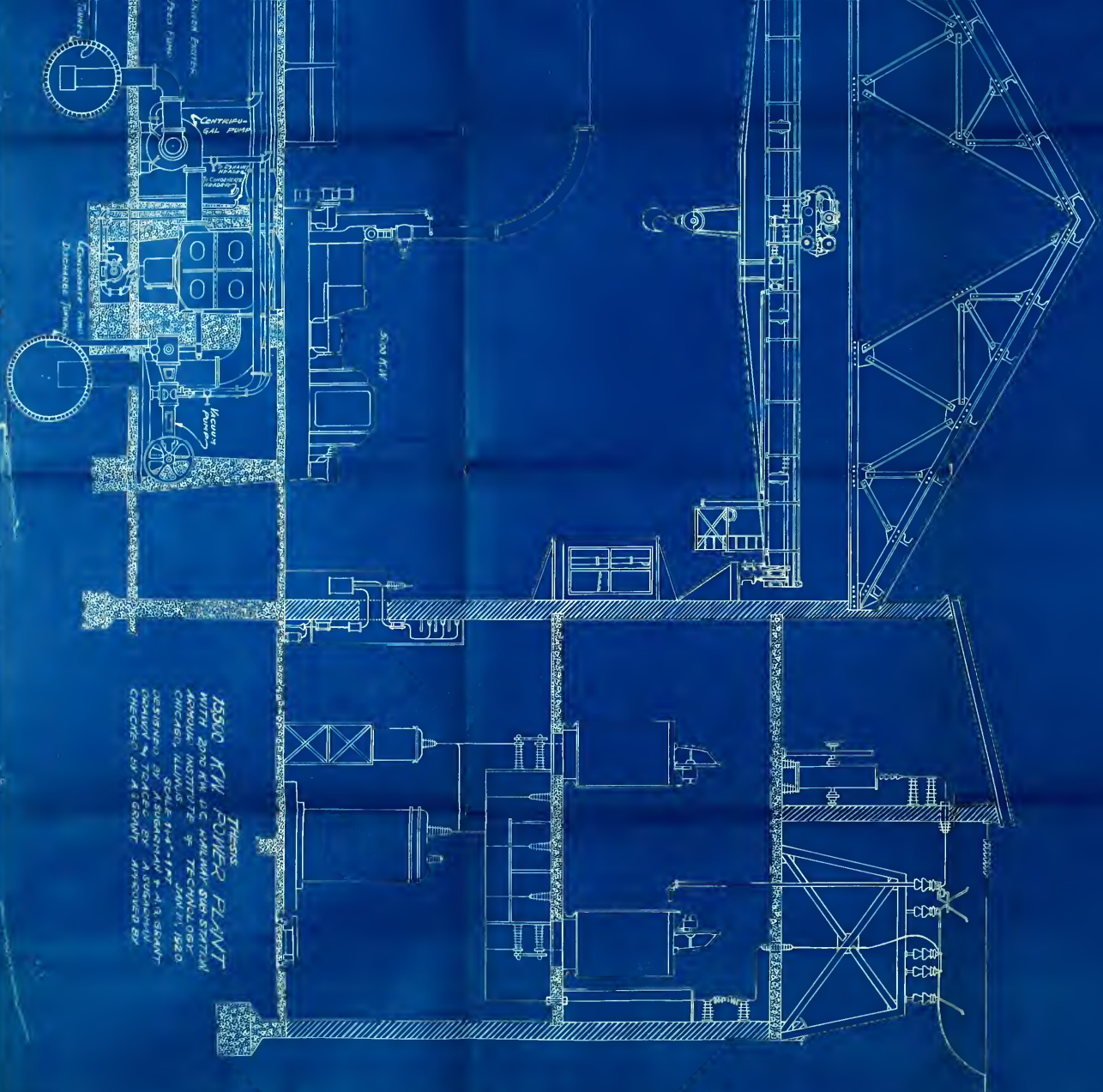
- Gebhardt, G. F.---Steam Power Plant Engineering.
John Wiley and Sons, New York.
- Allen and Bursley,---Heat Engines.
McGraw Hill Book Co. Inc. New York.
- Weingreen,---Electric Power Plant Engineering.
McGraw Hill Book Co. Inc. New York.
- Magnusson,---Alternating Currents.
McGraw Hill Book Co. Inc. New York.
- Standard Handbook for Electrical Engineers.
McGraw Hill Book Co. Inc. New York.
- Electrical Wires and Cables.
American Steel and Wire Co. New York.
- Steam Superheaters.
Babcock and Wilcox Co. New York.
- Steam.
Babcock and Wilcox Co. New York.
- Catalogues from the following companies:
- The Worthington Pump Co. New York, N.Y.
- The Wheeler Pump and Condenser Co. New York, N.Y.
- The Link Belt Co. Chicago, Ill.
- The General Electric Co. Schenectady, N.Y.
- The Westinghouse Electric and Mfg. Co. East Pittsburg, Pa.
- The Babcock and Wilcox Co. New York, N.Y.



THIS
REMOTE CONTROL SWITCHBOARD
FOR 15000KW GENERATING STATION
HARVARD INSTITUTE OF TECHNOLOGY
DRAWN BY H.S.
CHECKED BY H.S.







15,500 KW POWER PLANT
 WITH 200 KW D.C. AUXILIARY SYSTEM
 ARMOQUA, ILLINOIS
 DESIGNED BY T.C. WILSON
 JAN. 1, 1920
 DESIGNED BY T.C. WILSON & A. R. STANT
 FOR THE T.C. WILSON
 CHECKED BY A. R. STANT

THESES
 11 KW. POWER PLANT
 ADVANCE. 1930-1931
 INSTITUTE OF TECHNOLOGY
 22 ALBANY ST.
 BOSTON 21, MASS.
 Model No. 11-11, 11 kw. 110 volt 60 cycle
 power plant, for a 11 kw. 110 volt
 60 cycle power plant.

DISTRIBUTING BUS.
 GROUND-BUS.
 SYNCHROSCOPE BUS.
 FIELD-THETER BUS.
 CONTROL BUS.

UNIT # 1 5000 KW.

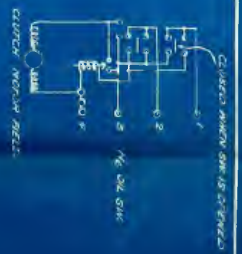
UNIT # 2 5000 KW.

LINE # 3

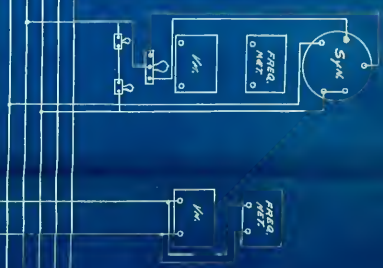
LINE # 4

HIGH TENSION BUS

CHOKE COILS.



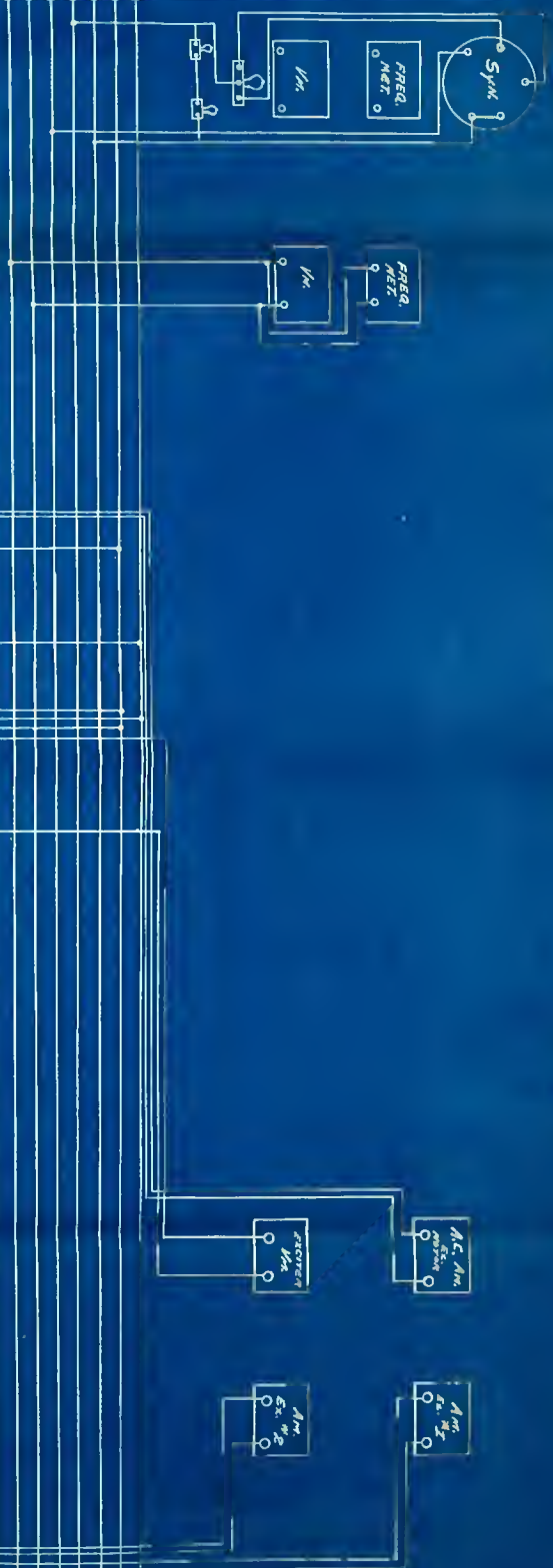
INTERNAL CONNECTIONS OF ONE SWITCHING



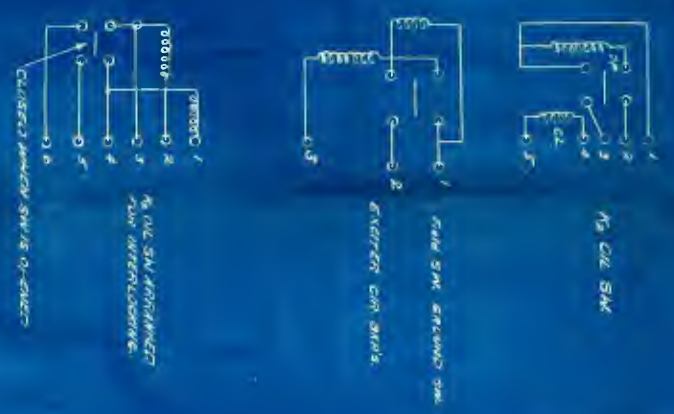
GROUNDING BUS

FIELD BUS

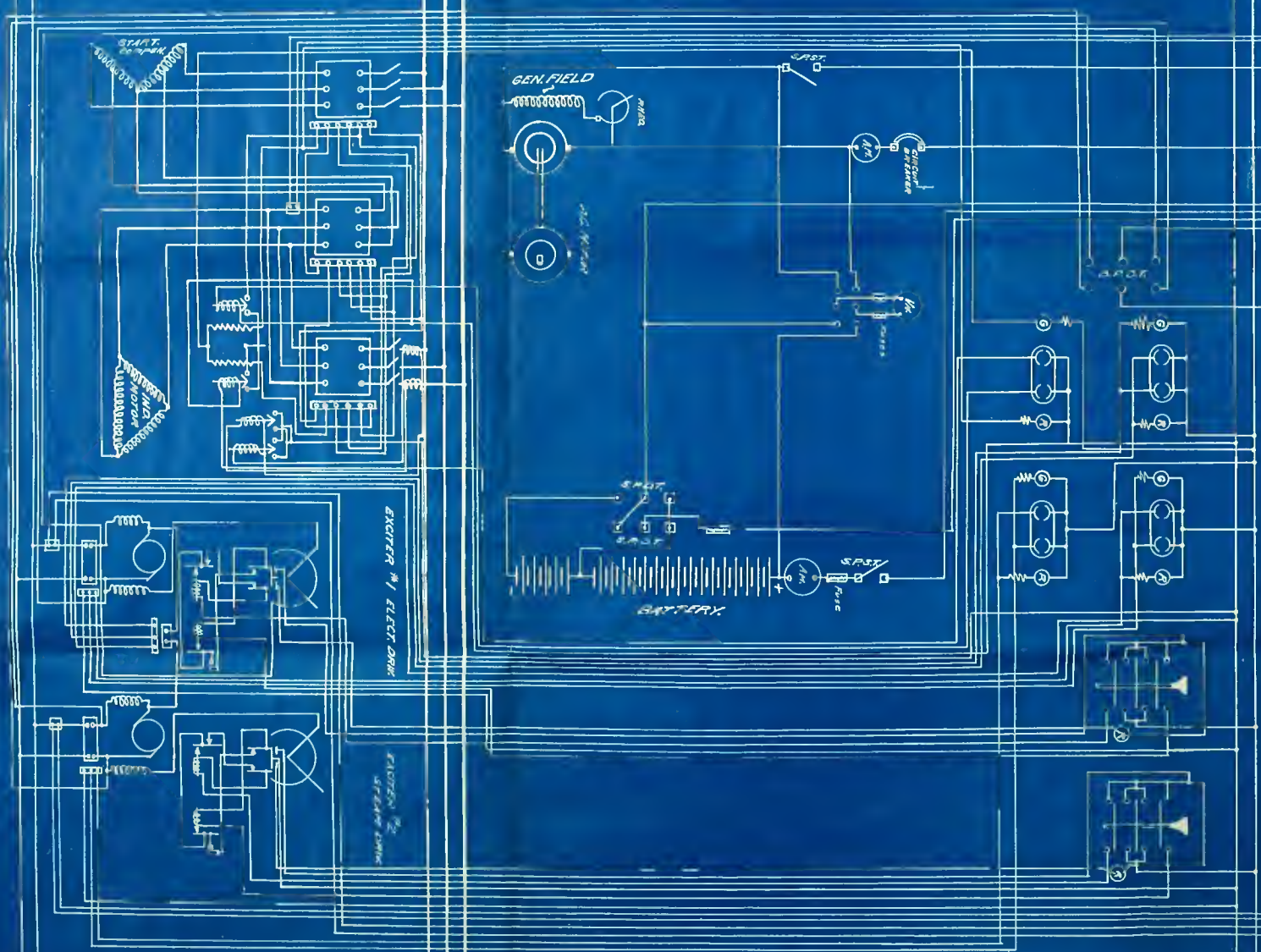
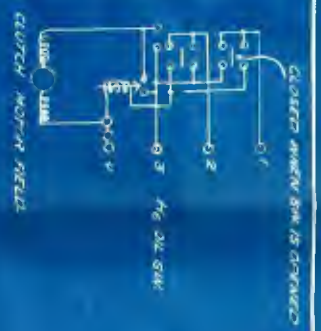
LOW TENSION BUS



TERMINAL CONNECTIONS OF
THE SWITCHES

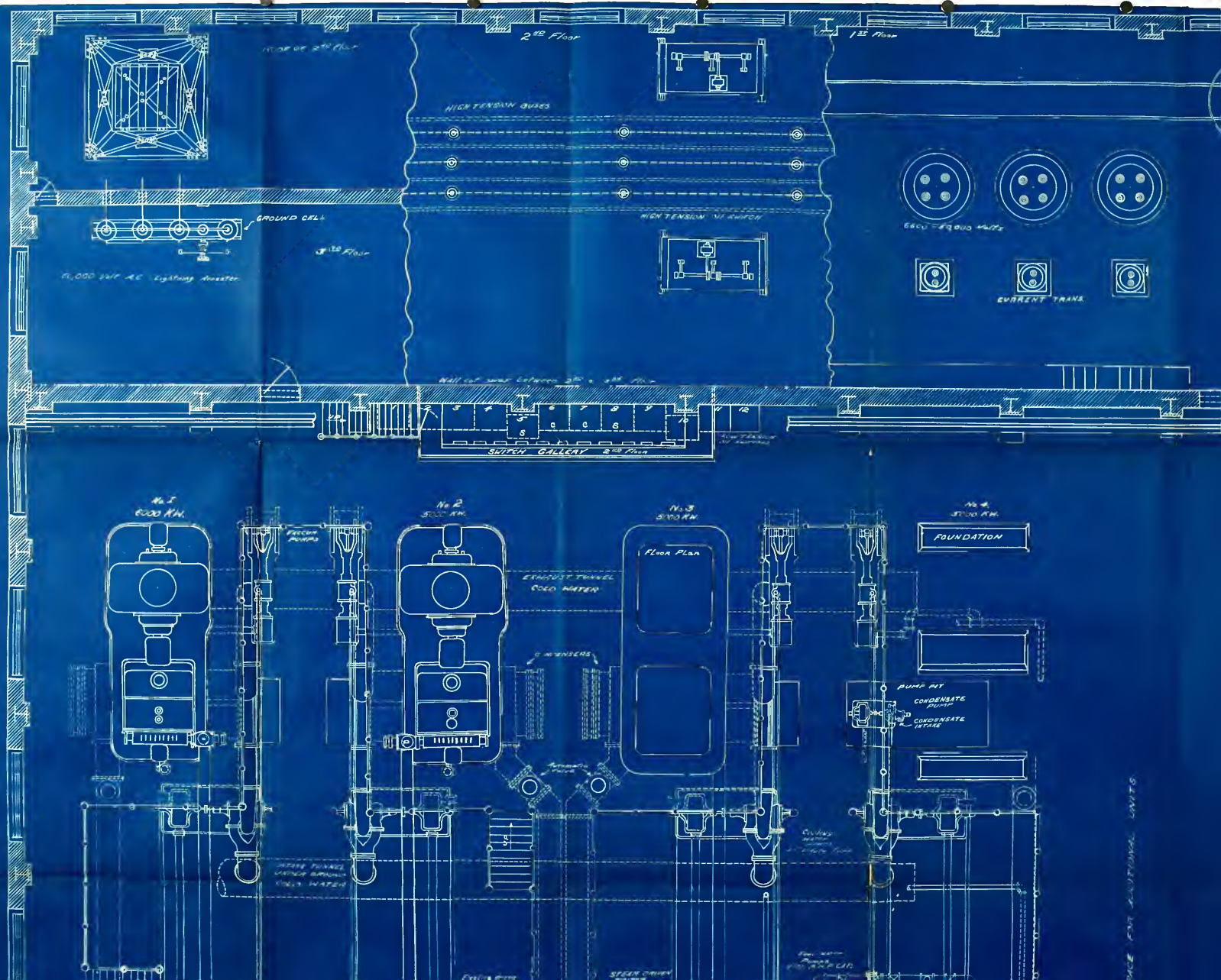


SWITCH WIRING



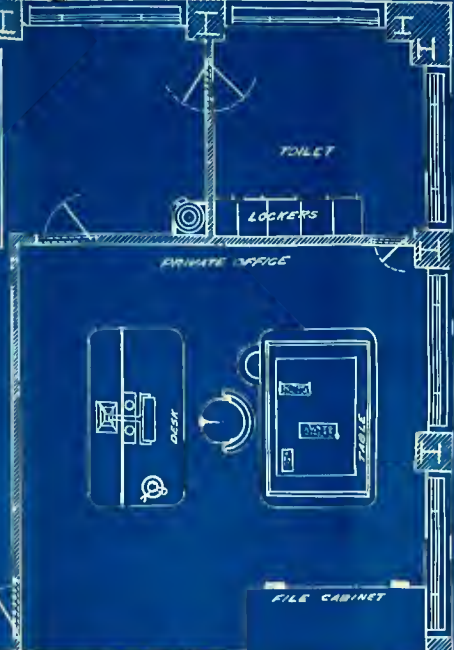
FIELD BUS

GROUND BUS



SPACE FOR ADDITIONAL UNITS

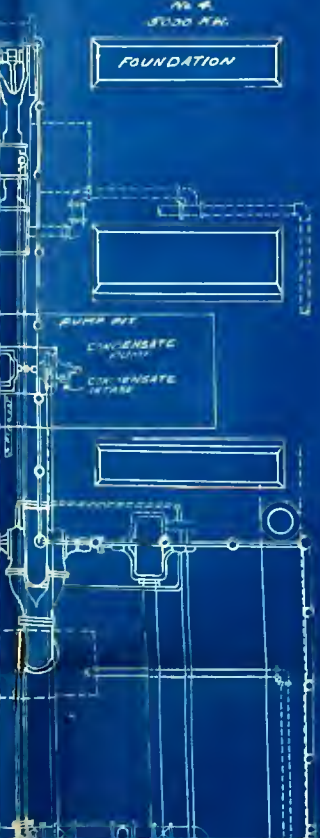
← THESIS →
15500 KW. POWER PLANT
 WITH 2500 KW. D.C. RAILWAY SUB-STATION
 AMALGAMATED INSTITUTE OF TECHNOLOGY
 CHICAGO ILLINOIS JAN. 2, 1920.
 — SCALE 1/4" = 1' —
 DESIGNED BY JAMES H. GARDNER & CO. ENGINEERS
 DRAWN & CHECKED BY J. H. GARDNER
 CHECKED BY W. L. APPROVED BY



FIRST FLOOR - OFFICE
 2nd FLOOR - GENERATOR

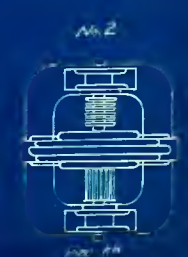
OFFICE

FOUNDATION



RESISTANCE No. 1

RESISTANCE No. 2



SUB-STATION N-1

SPACE FOR ADDITIONAL UNITS

